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PROVISIONAL INTELLIGENCE REPORT

COST AND REQUIREMENTS FOR PRODUCTION OF GYROSCOPES FOR A GUIDED MISSILE PROGRAM IN THE USSR

CIA/RR PR-147
12 September 1956

CENTRAL INTELLIGENCE AGENCY

OFFICE OF RESEARCH AND REPORTS

DOCUMENT NO. 1
NO CHANGE IN CLASS. ☐
☐ DECLASSIFIED
CLASS. CHANGED TO: TS S C
NEXT REVIEW DATE: 1989
AUTH: HR 70-2
DATE: 1 Oct 79 REVIEWER: 019360

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PROVISIONAL INTELLIGENCE REPORT

COST AND REQUIREMENTS FOR PRODUCTION OF GYROSCOPES FOR A GUIDED MISSILE PROGRAM IN THE USSR

CIA/RR PR-147

(ORR Project 34.596)

NOTICE

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CENTRAL INTELLIGENCE AGENCY

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FOREWORD

This report presents a first approximation of the cost, in terms of dollars, manpower, and floorspace, of the production of gyroscopes required to support a given (assumed) Soviet program for production of guided missiles.

The need for a study of precision mechanisms as they apply to production of guided missiles became apparent when the ORR Contribution to NIE 11-6-54, Soviet Capabilities and Probable Programs in the Guided Missile Field, 5 October 1954, TOP SECRET, was undertaken. One of the conclusions in that project was that the USSR might not have sufficient resources, especially in the fields of precision mechanisms and electronic equipment, to support the program for production of guided missiles that appeared to be indicated.

Although an all-source study of gyroscopes was made, no direct evidence could be found that would permit the calculation of estimates based on Soviet data. As it does in NIE 11-6-54, the methodology for this report therefore centers primarily around US analogy.

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COST AND REQUIREMENTS FOR PRODUCTION OF GYROSCOPES FOR A GUIDED MISSILE PROGRAM IN THE USSR*

Summary

Production of gyroscopes, or gyroscopic systems,** required for a guided missile program of the magnitude described in NIE 11-6-54 should not place an undue burden upon the precision mechanisms industry of the USSR. This conclusion has added significance because gyros account for an important part of the cost of complex precision mechanisms in guided missiles. It is not known, however, whether or not the gyro industry of the USSR has expended the economic effort necessary to meet the requirements of such a guided missile program.

Examination of simple aircraft instrument gyros and other Soviet equipment has indicated that the USSR has been successful in simplifying designs for production. The reduction of cost through the simplification of design is offset by the lower productivity of labor in Soviet industry. Reports by the US automation experts who recently visited the USSR indicate that the USSR does have some modern, high-quality machine tools and instruments. This equipment undoubtedly is available for production of components such as gyros in high-priority programs for guided missiles. No attempt has been made at this time, however, to quantify the net effect of the differing factors affecting production in the US and the USSR.

If the requirements for production of gyros for aircraft are added to the requirements for production of gyros for guided missiles on a single-shift basis, a conservative estimate of the range of the maximum annual requirements for production of all gyros in the USSR would be as follows: manufacturing cost, US $86.5 million*** and $121.5 million; total labor (including indirect), 12,500 and 18,500 persons; and floor-space, 1 million and 1.5 million square feet. In most years the annual requirements may be as much as 50 percent less than the higher figures in these ranges.

* The estimates and conclusions contained in this report represent the best judgment of ORR as of 1 July 1956.

** Hereafter referred to as the gyro, or gyro system.

*** All dollar values are given in US dollars throughout this report.

Approximately 25 to 35 percent of the workers needed for production in the gyro industry will require more than 1 year of training. The hypothetical Soviet program of production of gyros for guided missiles, therefore, should require in most years approximately 2,000 highly skilled persons; and the total gyro program for guided missiles and aircraft, less than 3,000 highly skilled persons.

The conclusions of this report are first approximations based on US analogy. Because of lack of information, definitive conclusions based on Soviet data cannot be drawn. The conclusions based on US analogy, however, are believed to be valid, even though the magnitude of the estimates may be somewhat in error.

I. Introduction.

A. General.

As a first step in determining the requirements for precision mechanisms in the Soviet guided missile program, it was decided to study gyros. This decision was based on the following considerations:

1. Gyros are highly developed precision mechanisms that have been troublesome in the US guided missile program.

2. Gyros account for a large part of the cost of the precision mechanisms in guided missiles.

3. Gyros are more homogeneous than the general term precision mechanisms and therefore make a more suitable classification for study.

Within the US intelligence community there was a widespread recognition of the importance of gyros as applied to guided missiles, but there was no readily available reference as to requirements by classes or cost of manufacture, either in terms of dollars or in terms of labor and equipment. This report classifies gyros used in guided missiles and discusses dollar costs, labor, floorspace, and similar factors in production in terms of the gyro industry in the US.

The numbers and classes of gyros required for the illustrative Soviet guided missile program in NIE 11-6-54, with the major modification suggested by NIE 11-12-55, are determined by the numbers and classes used in similar US missiles. The cost, labor, and floorspace necessary to fulfill these requirements are determined by applying US factors of production. Some of the assumptions implicit in applying US data to Soviet production are critically examined on the basis of what is known of Soviet production of similar, although simpler, items.

This report reaches conclusions as to the general magnitude of the effort required to produce the gyros for a guided missile program.

B. Use of Gyroscopes in Guided Missiles.

The gyro, or gyro system, has a threefold application in guided missiles. Probably the most common use is for attitude reference and stability in the autopilot system of the guided missile. Second, gyros are used for fire-control purposes, such as radar or infrared seeker stabilization. Third, certain guided missiles with inertial or partially inertial systems of navigation require highly precise gyros, or gyro systems, for purposes of guidance.

It is theoretically possible to design guided missiles without gyros. In German practice in World War II and in US practice, however, at least 1 gyro and and usually 3 or more have been used. In fact, the trend appears to be to increase the number of gyros used in US guided missiles. For example, the Terrier -- a type of US guided missile -- now uses two gyros, a roll free gyro and a roll rate gyro. In order to obtain better performance -- that is, higher altitudes and longer ranges -- a 4-gyro and 2-accelerometer system is being considered. The Talos, Nike,* Sparrow I, Bomarc, and Falcon types of guided missiles are all designed to use four gyros.

For inertial navigation, especially for the longer range guided missiles, a stable platform,** or stable element, is generally used. The stable platforms in the US frequently use three single-degree-of-

* See Figures 1 and 2, following p. 8.
** See Figure 3, following p. 8.

freedom gyros.* The stable platform for the NAVAN system uses 6 gyros, 2 on each axis.** Present practice in the US indicates an increasing dependence upon gyros for navigational and stabilizing functions. The class of gyro, the degree of precision, and other characteristics required to perform a certain function in a guided missile may vary, however, depending upon the design and the associated equipment selected. For example, a single two-degree-of-freedom amount gyro*** may be used to provide attitude information, or the same information could be obtained by the use of two single-degree-of-freedom gyros.

C. Major Differences Between Gyroscopes Used for Guided Missiles and Others.

There are no substantial differences between the gyros used for certain types of guided missiles and those used elsewhere -- for example, in aircraft. Guided missiles such as Petrel, Dove, D-40, Dart, and similar types, in which the gyro is used largely for stabilization and in which the speed of flight of the guided missile is relatively low and the time of flight short, can and do use gyros that are the same or similar to those used in aircraft. Similarly, certain types of guided missiles such as the Matador, Regulus, Snark, and similar glide or pilotless aircraft-type missiles may require certain gyros

* See Figure 4, following p. 8.

** The purpose of two single-degree-of-freedom gyros on each axis is to get greater accuracy with somewhat less precise gyros -- to be accomplished by mounting a pair of gyros on each axis. One gyro from each NAVAN pair is used to stabilize the platform at any one time. The control is periodically switched from one gyro of the pair to the other. During the time that a gyro is not controlling the platform, it is caged about its output axis, and the motor excitation is reversed to bring the gyro up to speed in the reverse direction. When the gyro is up to speed in the reverse direction, control is returned to it, and the second gyro undergoes the NAVAN reversal. The reversing of spin is expected to reduce greatly drift of the stable platform. A report on guidance systems states, "The NAVAN method of accurately controlling the orientation of a stabilized platform is based on the fact that the undesirable effects of constant or slowly changing bias torques about the output axis of a gyro can be greatly reduced by periodically reversing the direction of gyro rotation." 1/ (For serially numbered source references, see Appendix D.)

*** See Figure 5, following p. 8.

that have the same or similar characteristics as the gyros required by modern aircraft. As the performance characteristics of aircraft increase, the class of gyros required will change. Thus many of the components of aircraft now being designed must be as good as or better than the components used in many of the present-day guided missiles.

Despite the similarities discussed above, there are differences between gyros for guided missiles and other classes of gyros. The most important differences are as follows:

1. The considerably greater precision required in many gyros for guided missiles, especially those used for inertial navigation.

2. The ability to withstand a wider range of environmental factors, especially much higher vibrations, greater shocks or acceleration, and higher temperatures.

3. The smaller size and lighter weight of gyros designed primarily for guided missiles.

4. The high degree of reliability required on a one-time basis.

In the early designs of many of the US guided missiles, gyros developed for other applications were used insofar as possible. In general, however, with the exception of some of the slower, shorter range guided missiles, the results were not satisfactory, and new classes of gyros were developed for guided missiles. In some cases these new classes have been used for aircraft, even though the performance of the new class of gyro exceeds requirements. A US industrial handbook states in regard to one class of gyro:

> "... It meets the technical requirements for fire-control computing at an unusual saving in cost while simultaneously its use for artificial damping in aircraft autopilots is economically justified though its performance is far better than needed." 2/

D. Classification of Gyroscopes.*

1. Technical Classification and Definition of Terms.

A useful system of classifying gyros, which is frequently used in technical literature, is based on the freedom from rigid restraint of the gyro spin axis.** It can have a maximum of 2 degrees of freedom,*** that is, only 2 angular coordinates are required to specify its orientation exactly. In the usual configuration of gyro instruments, these 2 angles may be taken as the angular position of the 2 gimbals**** supporting the gyro element. Thus a gyro supported in 2 gimbals would be a gyro with 2 degrees of freedom, even though the gyro were subjected to some torques about either or both of the gimbal axes. A gyro supported in only one gimbal, on the other hand, would have the position of its momentum vector determined by only one angular variable and would be called a single-degree-of-freedom gyro, or a rate gyro.** Amount gyros normally have 2 degrees of freedom, and single-degree-of-freedom gyros, or rate gyros, have 1 degree of freedom. The amount gyro operates free of any restraint upon the orientation of the gyro rotor***** other than small torques, whereas the rate gyros are captive in that the gyro spin axis is forced to

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* This section draws heavily on the publications listed under source 3/. These publications may be consulted for a fuller discussion of gyroscope theory and a further definition of terms.

** See Figure 6, following p. 8.

*** The meanings of certain technical terms used in connection with gyros are not matters of universal agreement. For example, one definition of degrees of freedom is: "A body has as many degrees of angular freedom as there are orthogonal axes about which it may turn relatively to the support. Unless it has 3 degrees of freedom (1 being about the spin axes) a gyro cannot be carried without disturbance in a craft subject to roll, pitch and yaw." 4/ Under this definition of degrees of freedom, an amount gyro would have 3 degrees of freedom and a rate gyro would have 2 degrees of freedom. This report refers to degrees of freedom in the sense of the freedom from rigid restraint of the gyro spin axis.

**** A gimbal is a contrivance for permitting a body to incline freely in any direction, or for suspending anything, such as a compass, so that it will remain plumb, or level, when its support is tipped. See Figure 5, following p. 8.

***** See Figure 5, following p. 8.

move with the movement of the vehicle (guided missile or aircraft). As their names imply, the amount gyro instruments measure the angular deviation of the vehicle from reference directions, whereas the rate gyro instruments measure the rate of change of these angles. Amount gyros are also called vertical gyros, directional gyros, or free gyros.

A special class of single-degree-of-freedom gyro is the so-called "rate integrating gyro." The rate integrating gyro is a single-degree-of-freedom gyro in which precession* relative to the frame is opposed by the viscous drag of the fluid in which the rotor is floated. The total deviation of the gyro around one axis from a datum line on the base is a measure of the total deviation of the base around a perpendicular axis from a datum line in space. The rate integrating gyro unit** is basically a device in which the gimbal angle is restricted to small values because of interfering effects that appear when the angular momentum vector tilts far enough with respect to the case, or outer shell, to acquire an appreciable component along the input axis.* This feature does not detract from using this class of gyro on stable platforms as the stabilizing element. Single-degree-of-freedom gyros, with or without the integrating feature, are normally used on stable platforms in the US.

2. Other Possible Classification Systems.

Gyros may be classified in many other categories, depending upon the purpose to be served. Among the possible criteria for classification are the degree of precision of the instrument, the function for which the gyro signals are desired, the size, the type of power used to drive the rotor, and the character of the input or output element in intimate association with the gyro element.

Precision is one of the most important characteristics in classifying gyros used in guided missiles.*** A classification based on precision alone, however, is incomplete. The following characteristics must be taken into account: sensitivity of readings; ruggedness, or the ability to withstand shock of acceleration and vibration; weight

* See Figure 6, following p. 8.
** See Figure 4, following p. 8.
*** See Figure 7, following p. 8.

and size -- light and small enough to fit into the space available; ability to operate satisfactorily in the ambient temperature range of the particular application; rapidity of speed-up time, or the time required for the gyro to get up to operating speed after power is applied; and availability of the amount and type of power required in the guided missile.

If gyros are classified on the basis of precision, the assumption must be made that these other characteristics of the gyro are sufficient for the application desired. Although this assumption may seem far-reaching, it is not entirely unrealistic. There is generally a high correlation between precision and sensitivity of readings. Few producers will go to the effort and expense of manufacturing a highly precise gyro without attempting to put sensitive pick-offs* on it. To a certain extent there is a correlation between precision and ruggedness. The higher precision gyros are frequently floated gyros.** Because they are floated in a viscous fluid, they are able to withstand large shocks and vibrations. With the exception of air-to-air guided missiles in which size and weight are at a premium, there is considerable latitude as to weight and size of gyros. Other factors being equal, however, the smaller, lighter gyro will be selected. There is a tendency to provide heaters for many gyros and to provide air-conditioning for certain of the guidance compartments. In fact, the temperature of floated rate integrating gyros must be controlled within narrow limits. The tendency is, therefore, to use equipment such as heaters and/or air conditioners to maintain temperatures within the operating range rather than to build wider temperature operating limits into the gyro itself. Speed-up time is important in defense-type guided missiles, such as the Nike, Terrier, Bomarc, and others, which must be on standby status. The problem of speed-up time may be solved by having an external source of standby power which can be switched on during an alert status. The nonfloated gyros can be brought up to operating speed quickly by using a compressed-air or a powder charge as a motive force or by designing the electric motor to operate when considerably overloaded. This characteristic of rapid speed-up is of little importance in the offensive-type missiles in which firing time can be selected in advance. Although the type of power and the amount of power available in a guided missile may limit

* See Figures 5, 6, and 7, following p. 8.
** See Figure 4, following p. 8.

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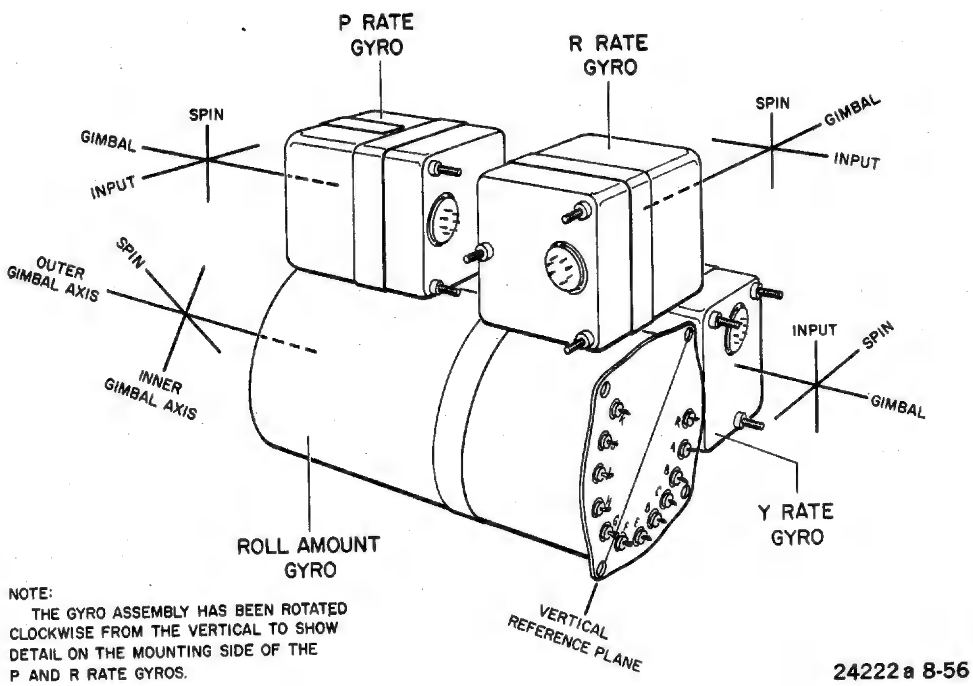

Figure 1. Orientation of Gyroscopes in Nike.

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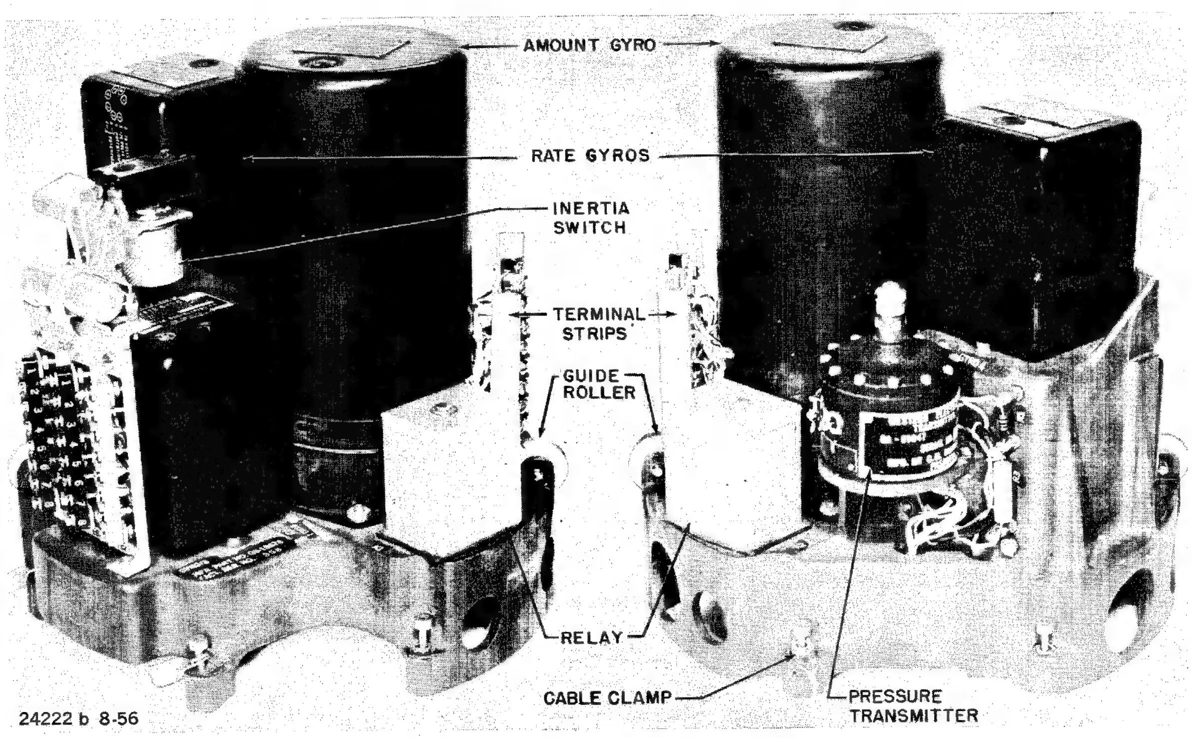

Figure 2. Gyroscope Section of Nike.

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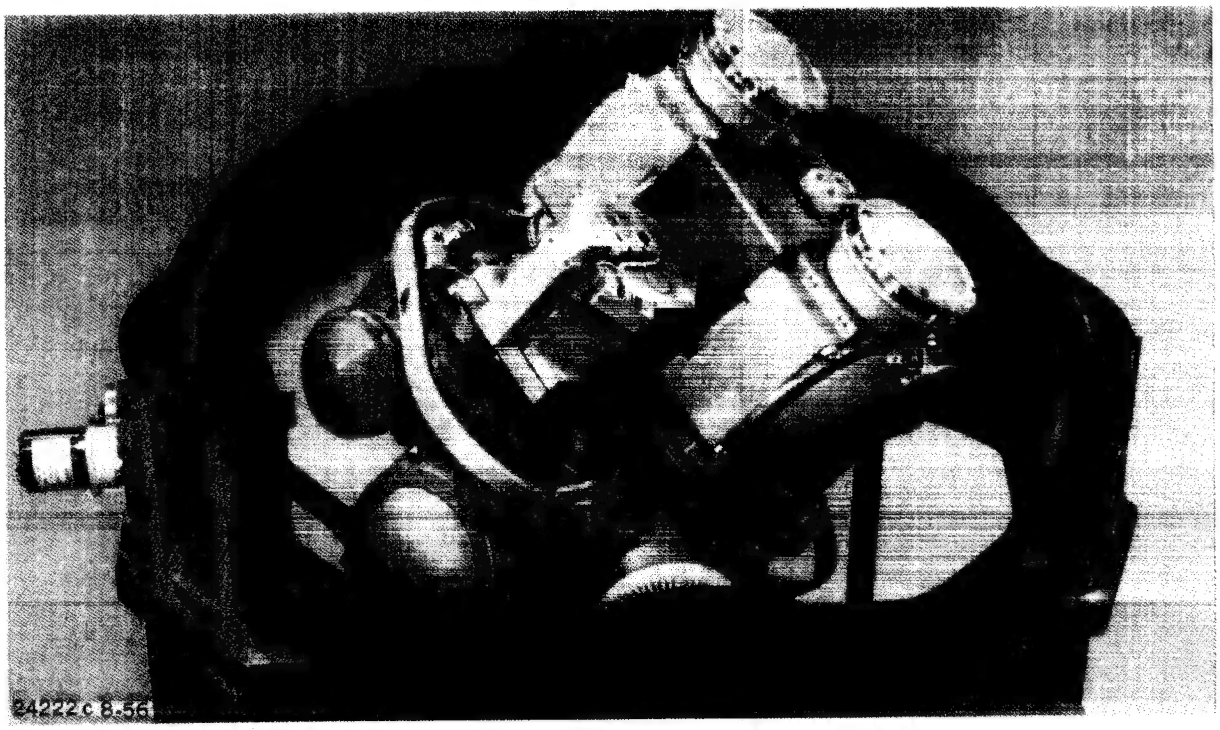

Figure 3. View of Stable Platform.

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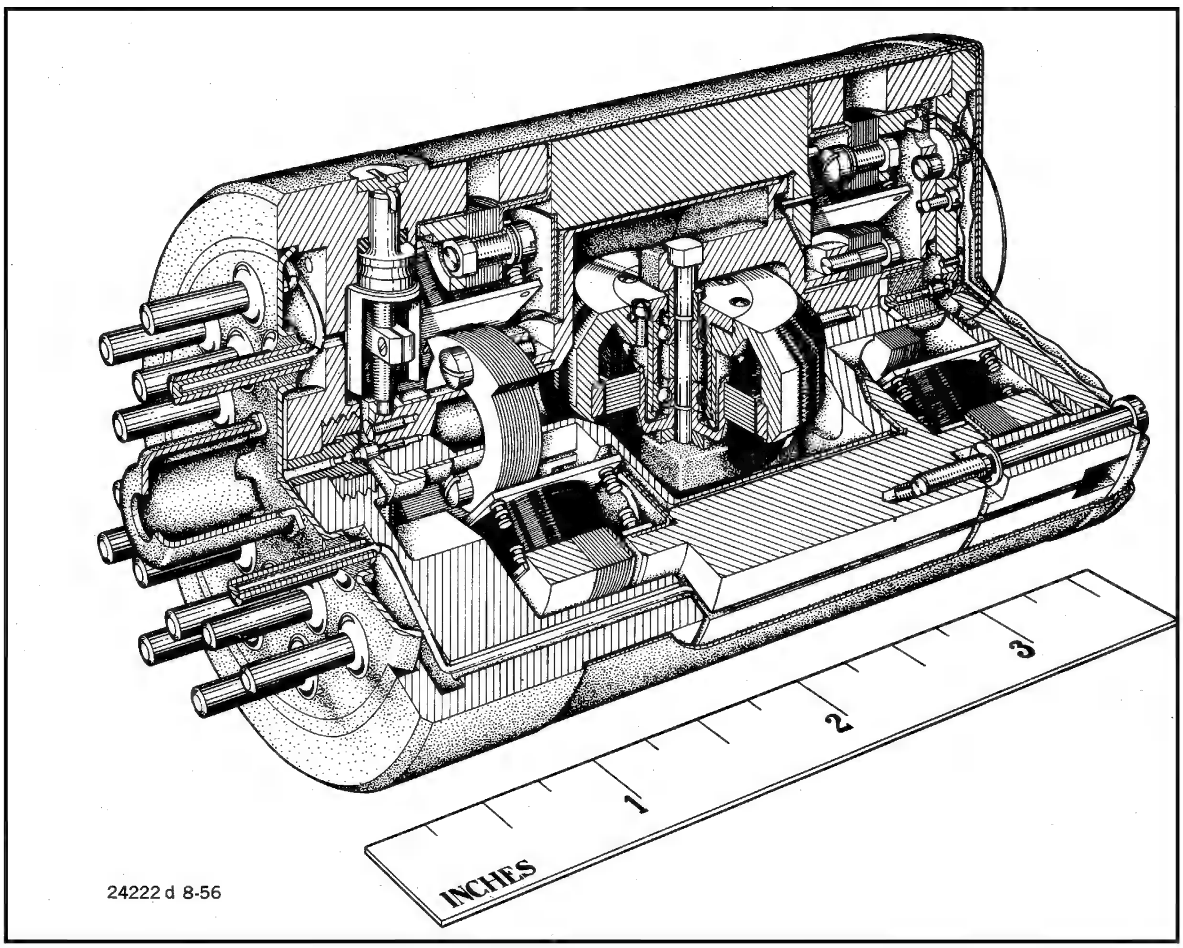

Figure 4. Sectioned View of Single-Degree-of-Freedom Floated Gyroscope.

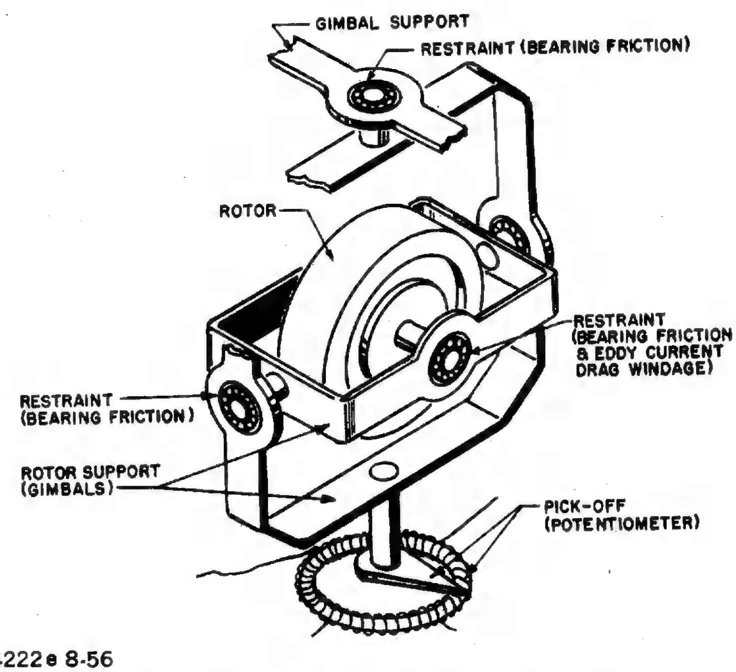

Figure 5. Simple Amount Gyroscope.

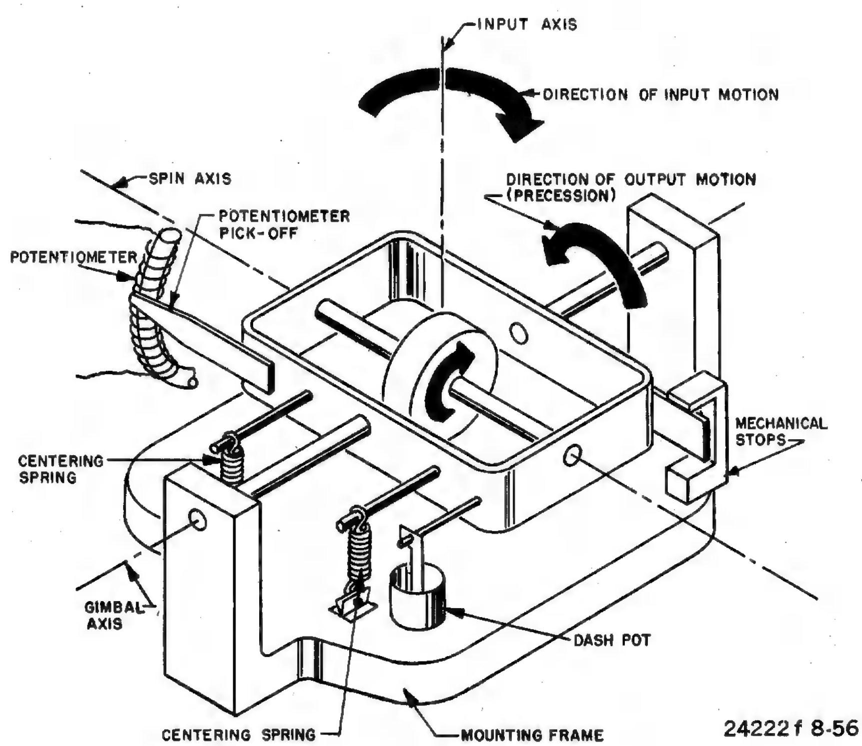

Figure 6. Simple Rate Gyroscope.

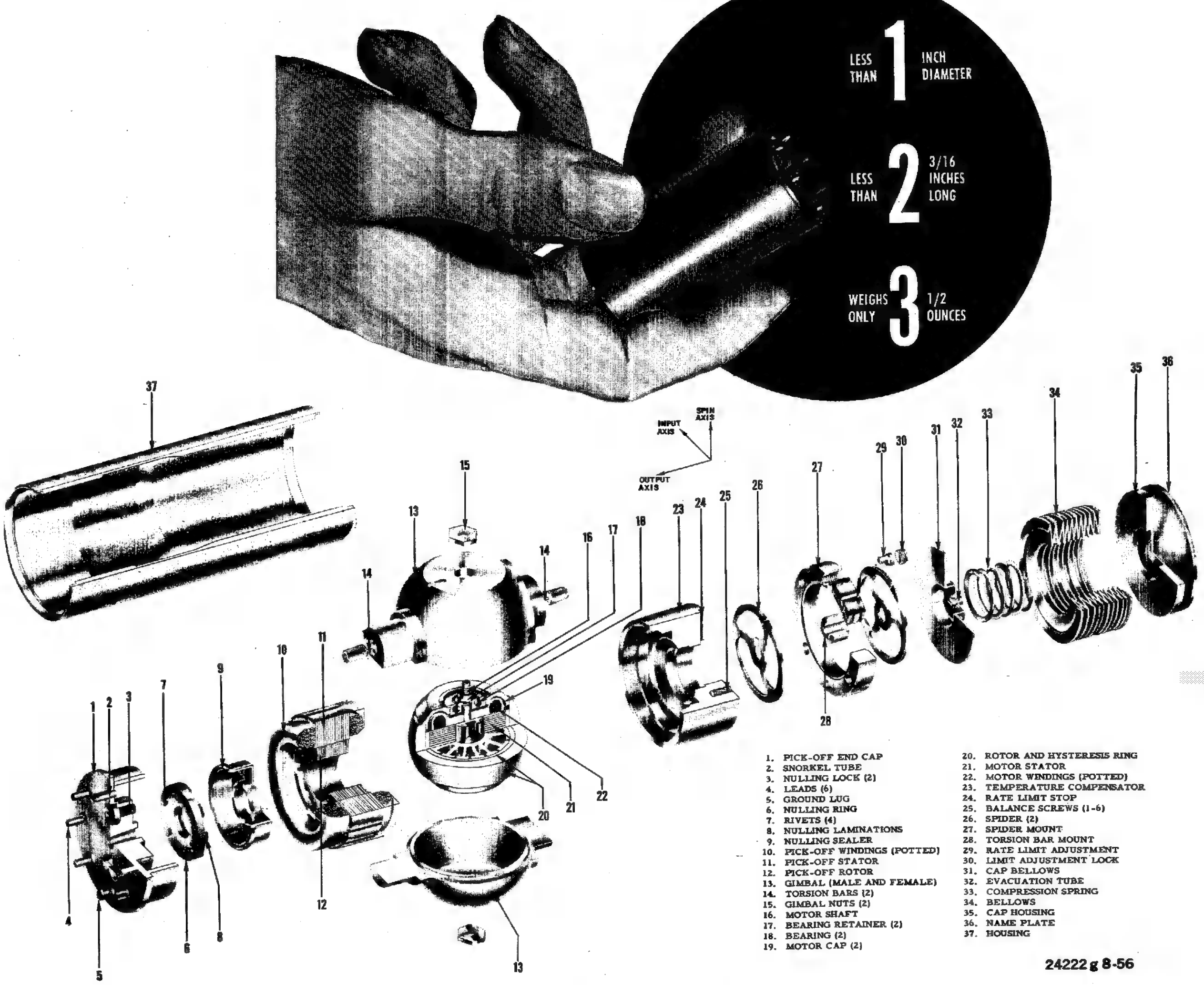

Figure 7. External and Exploded Views of Subminiature [illegible] Gyroscope.

the choice of existing gyros, there are usually no serious obstacles to designing a gyro to use the power that is available. There is a trend in the US to make 400-cycle-per-second, 115-volt alternating current available in guided missiles. Some guided missiles such as the Nike, however, operate on direct current.

A classification based on the function for which the gyro signals are desired is similar in results to a system based on precision. This system of classification, based on function, would result in three major classes: navigational; fire-control, or seeker, stabilization; and attitude stabilization. Generally, navigational gyros must be highly precise; fire-control, or seeker, stabilization gyros may be less precise; and attitude stabilization gyros, still less precise.

Classification systems based on size, type of power used, or the character of the input or output element associated with the gyro element are too restricted in scope for the purposes of this report and will not be discussed.

3. Classification System Used in This Report.

The preceding discussion indicates some of the difficulties in making a simple classification of gyros. By combining precision, usage, and degree of freedom, it is possible to classify gyros in a relatively definitive manner which will be useful in evaluating the economic factors involved in production of gyros. The classification used in this report is as follows:

a. Highly precise gyros, such as floated gyros for navigation (single-degree-of-freedom) -- drift rate of 0.1 degree per hour or less.

b. Relatively precise amount gyros for fire control -- drift rate of approximately 1 degree for 5 minutes.

c. Relatively precise rate gyros for fire control -- drift rate equivalent to approximately 5 degrees per hour and a dynamic range* of more than 1,000 to 1.

* Dynamic range is the ratio of maximum rate measured in degrees per second divided by the minimum rate measured in degrees per second.

d. Moderately precise amount gyros for attitude stabilization -- drift rate up to 1 or 2 degrees per minute.

e. Moderately precise rate gyros for attitude stabilization -- simple rate gyros with dynamic range of 100 to 1 or better.

f. Relatively crude amount gyros for attitude stabilization -- drift rate of several degrees per minute.

g. Relatively crude rate gyros for attitude stabilization -- simple rate gyros with dynamic range of less than 100 to 1.

It should be noted that in the US the highly precise gyros used for navigation have been mostly single-degree-of-freedom gyros on a stable platform.* A stable platform, or a stable element, consists of a suitable gimbal structure which is kept oriented in space, or caused to maintain a fixed relationship with the earth, by means of gyros and allied equipment mounted thereon. The platform normally serves as a base for accelerometers, star-tracking telescopes, or similar equipment. The platforms considered in this report are stabilized by 3 single-degree-of-freedom gyros, such as floated rate integrating gyros, and have 3 movable gimbals. Instead of 3 single-degree-of-freedom gyros, a platform could be stabilized with 2 two-degree-of-freedom (or amount) gyros.

II. US Factors of Production.

A. Cost.

1. Concept Used in This Report.

Cost is not a precise term. To the producer of guided missiles, the cost of the gyro is the price that he pays for the completed gyro. To the producer of gyros, the cost of the gyro is a figure which includes labor, materials, amortization of plant and equipment, developmental expense, administration and general expense, selling expense, and other miscellaneous expenses. In this report, the term cost means cost of manufacture. Thus labor, materials, and

* See Figure 3, following p. 8, above.

plant overhead are included. Excluded are certain legitimate expenses of doing business, such as administration, sales, and developmental expense, which may be substantially incurred outside the producing firm. For items that are newly developed, the estimate of the cost may be influenced to a degree by developmental cost. In general, it is believed that the costs given in this report do not reflect development to any significant degree.

For the purposes of this report, it was believed that the cost of manufacture was a more useful factor than total cost or selling price. In other economies, for example, the economy of the USSR, the components of the cost of manufacture will tend to be relatively comparable to those in the US. Components of cost such as selling, administration, and the like, however, may be quite different. The developmental cost of a particular item is a one-time expense that ends once the phase of research and development is completed, and it does not affect the cost of producing additional units of the item.

The omission of developmental costs in this report does not imply that the development of gyros is not a large item of expense in a guided missile program, whether measured in terms of dollars or in terms of labor. The emphasis in this report, however, is on factors required for production and the cost of manufacture after development has been completed.

An approximation of the relationship of the selling price of a single specially designed item and the cost of manufacture of the same or of a similar item can be gained from the following example. A recent request for bids on an inertial guidance system for a medium-range guided missile brought forth bids ranging from $150,000 to more than $700,000. The lowest bidder indicated that the cost of a guidance system of this degree of precision was divided approximately as follows: 55 percent for electronics and 45 percent for the stable platform. The allocation to the stable platform is, therefore, approximately $67,500 (45 percent of $150,000). The lowest bidder also indicated that a stable platform of a similar type and degree of precision would cost $7,500 each to produce at a rate of 100 units per month. The relationship between the selling price for a single unit, which includes developmental cost, and the cost of quantity production -- 100 units per month -- is 9 to 1: that is, the single unit selling price is 9 times the unit cost of manufacturing the item in production quantities. The estimated cost of manufacture at the rate of 1,000 units per month is $5,700 each, a ratio of approximately 12 to 1.

To be meaningful, cost must be related to the level of production. The unit cost of manufacture of a specific class of gyro will be much higher for small quantities than for large quantities. With very low rates of production the cost of tooling and jigs and fixtures must be amortized over a few units. If the tooling is cut down to take this factor into account, then machinists of greater skill must be employed to maintain the precision otherwise given by the jigs and fixtures.

At very low rates of production, jobs cannot be broken down into their simplest components and assigned to different individuals. Instead, each individual must do several tasks, which generally means that higher skills are required of the workers but that these higher skills are employed only part of the time. Moreover, switching from task to task is not so productive as specializing in one task.

As production increases, the total overhead does not increase at anything like the same rate. To produce even very small quantities, special equipment is needed to do each of the required tasks. As production is increased, however, only certain items of equipment must be increased. Because the total cost of the equipment is spread over more units, the unit cost decreases. The same argument applies to indirect labor involved in production.

Typical costs of manufacture for the various classes of gyros based on the estimates of producers indicate that the unit cost of manufacture at a monthly rate of 1,000 units per month is approximately 80 percent, and at a rate of 10,000 units per month, approximately 65 percent, of the cost at the rate of 100 units per month.* Although figures on cost generally are not given for less than 100 units per month, the limited available information indicates that the cost of manufacture at a rate of 50 units per month is approximately 150 percent of the cost at a rate of 100 to 200 units per month, and the cost of manufacture at a rate of 10 units per month is almost 300 percent of the cost at a rate of 100 to 200 units per month. Other information indicates that a volume of 10 units per month would be "very costly" without estimating an amount.

* At a rate of production of 1,000 units per month, the range for the 7 classes of gyros is from 71 to 86 percent of the cost of 100 units per month, with both the median and the mean falling at 79 percent. At 10,000 units per month, the range is from 57 to 69 percent, with the mean, median, and mode all falling at 63 percent.

2. Cost of Manufacture.

Table 1* shows the typical US cost of manufacture per unit of various classes of gyros and stable platforms at various rates of production. This cost is derived from estimates of the performance of leading US gyro producers and therefore indicate general trends for classes of instruments rather than exact figures taken from records. There is no one criterion for classifying gyros into separate classes without some degree of overlap. In practice, therefore, the cost of manufacturing individual gyros ranges from high to low without distinct breaks because of the varying degree of precision, resolution, ruggedness, and other characteristics built into the particular gyro designed for a particular application. In Table 1 an attempt is made to assign a specific value representative of the class, based on a range of values. This table must be used with the caution which should normally be given to "average" figures.

Table 1 shows that at comparable rates of production the highly precise gyros for navigation are less expensive to produce than the relatively precise amount gyros for fire control. The highly precise class of gyro represented is a single-degree-of-freedom gyro with only 1 sensitive axis, whereas the relatively precise amount gyro has 2 degrees of freedom: that is, 2 sensitive axes. Likewise, amount gyros and rate gyros of the same relative degree of precision have considerably different costs of manufacture.

Table 1 does not include data representing the type of stable platform which is likely to be used in an intercontinental ballistic missile (ICBM) such as the Atlas. The stable platform included in Table 1 is the type that might be used with a short-range ballistic missile or with a cruise-type missile using star-tracking, ATRAN,** or some other type of aided inertial navigation.

The data presented in Table 1 on relatively crude rate gyros are limited in scope. The table does not include information on the gyros used in short-range, short-time-of-flight missiles, such as the Dart, the D-40, and the like. The D-40 missile, for example, uses three sets of air-driven gyros. Each set contains two

* Table 1 follows on p. 14.

** ATRAN means Automatic Terrain Recognition and Navigation. In general, it consists of matching of radar returns against a previously prepared radar map of the route.

Table 1

Typical US Cost of Manufacture per Unit for Various Classes of Gyroscopes and for Stable Platforms at Various Rates of Production a/
1955

1955 US $

Class of Gyro	50 Units per Month	100 to 200 Units per Month	500 to 1,000 Units per Month	10,000 Units per Month
Highly precise single-degree-of-freedom (floated) gyros for navigation	2,000	1,335	1,150	900
Relatively precise amount gyros for fire control	2,250	1,500	1,250	950
Relatively precise rate gyros for fire control	1,050	700	500	400
Moderately precise amount gyros for stabilization	1,425	950	750	600
Moderately precise rate gyros for stabilization	525	350	290	240
Relatively crude amount gyros for stabilization	750	500	375	310
Relatively crude rate gyros for stabilization	300	200	150	125
Three-gyro platform, or stable element	11,250	7,500	5,700	4,500

a. For derivation of the figures, see Appendix B, Methodology.

rotors, one mounted as an amount gyro and the other mounted as a rate gyro. The expected price of these sets is approximately $100 each at low rates of production. In the Dart, it is planned to use a powder-charge-driven amount gyro which spins on its own inertia during the 1-minute flight of the guided missile. This gyro is reported to cost about $80. 5/

B. Requirements for Direct Labor.

Table 2* shows the typical US requirements for direct labor per unit for various classes of gyros and stable platforms at various rates of production. This table is broken down in the same way and refers to the same gyros as Table 1.** The same limitations which apply to Table 1 also apply to Table 2.

In the production of gyros in the US, practices differ among companies in terms of the amount of subcontracting required. In certain companies the cost of raw materials and purchased parts is relatively high and direct labor hours are relatively low as compared with cost and labor requirements for somewhat similar gyros produced by other companies. The labor figures presented here have been adjusted to take into account differing practices among companies. The number of direct labor man-hours presented is believed to represent "average" US practice. US producers usually purchase such items as screws, nuts, bolts, and other hardware items; bearings; and certain standard electrical items such as potentiometers,*** glass sealed wires, and similar items. It is possible that few of these items would be purchased in the USSR, and more direct labor would therefore be required by the producer of gyros. Statements by Soviet leaders in recent months indicate that more items should be produced in specialized plants instead of being produced by the user.

C. Training and Skills.

1. Skills Required.

The production of gyros, as distinguished from their development, poses no peculiar problems in terms of skills required. The amount of skill required in the production of parts is dependent to a

* Table 2 follows on p. 16.
** P. 14, above.
*** See Figures 5 and 6, following p. 8.

Table 2

Typical US Requirements for Direct Labor per Unit for Various Classes of Gyroscopes and for Stable Platforms at Various Rates of Production a/
1955

Man-Hours

Class of Gyro	50 Units per Month	100 to 200 Units per Month	500 to 1,000 Units per Month	10,000 Units per Month
Highly precise single-degree-of-freedom (floated) gyros for navigation	335	225	185	140
Relatively precise amount gyros for fire control	345	230	185	140
Relatively precise rate gyros for fire control	180	125	95	80
Moderately precise amount gyros for stabilization	285	190	140	110
Moderately precise rate gyros for stabilization	120	80	65	50
Relatively crude amount gyros for stabilization	110	75	55	45
Relatively crude rate gyros for stabilization	50	35	25	20
Three-gyro platform, or stable element	1,575	1,050	775	625

a. For derivation of the figures, see Appendix B, Methodology.

large extent upon the level of production in a particular enterprise. In development and small-scale production the skill required to produce parts will necessarily be high because the end product requires parts manufactured to close tolerances. There are several methods by which these close tolerances may be attained. One method is to have highly skilled workers, using general-purpose machines, produce the parts in job lots. This method is almost invariably used during development and on small job-lot orders. A second method is to design and build a jig or fixture for use with the machines. With the help of jigs and fixtures, semiskilled workers can produce precision parts, assuming that the machine is built to hold to close tolerances. This method is economically justified if many parts are to be produced. A third method is to design and build a special-purpose machine to produce the part. This method, which is economically justified only for production in very large quantities, allows relatively unskilled workers to produce highly precise parts. Thus the skill may be required of the workers or it may be built into the machines.

In the US, many classes of gyros are produced by the first method. Those that are made in quantity are generally produced by the second method. It is unlikely that the gyro industry in the US will ever use the third method because of the multiplicity of designs and the number of companies producing gyros. If designs were standardized and production limited to 1 or 2 facilities, it is possible that the third method would be feasible. Without using the third method, however, the number and complexity of jigs and fixtures can be increased and the operations broken down into their simplest components if the production (demand for the gyros) warrants. Therefore, in addition to skilled workers who can perform many operations on numerous machines, the specialist may be developed. The specialist may be defined as a person trained to handle a particular machine. The semiskilled worker can perform a limited number of operations on one or more machines. There is no method of production that will entirely eliminate the skilled worker in this field. When production goes beyond the job-lot stage, however, with the aid of jigs and fixtures and careful planning of production, the job can be simplified in such a manner that the majority of the operators may be specialists or semiskilled workers.*

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* An examination of Soviet aircraft instruments indicates that the USSR is designing for simplicity of production (see Appendix A).

The level of skill required in production of parts of gyros is greater than that required for assembly. In a US plant, for example, 20 percent of the workers may be fully skilled; 70 percent, skilled on 1 machine; and 10 percent, semiskilled. This plant, however, handles small series production. For larger scale production a somewhat greater percentage of semiskilled workers would suffice.

In assembly operations a large percentage of the workers are semiskilled. In assembling a certain class of rate gyro in a US plant, for example, 25 percent of the labor may be unskilled; 65 percent, semiskilled; and 10 percent, skilled. On gyros of moderate precision and complexity, it was estimated that 20 percent of the labor could be unskilled; 60 percent, semiskilled; and 20 percent, skilled. On high-precision gyros, it was estimated that only about 5 percent could be unskilled; 55 percent, semiskilled; and 40 percent, skilled. In assembly work the major factor which varies the amount of skill required is the amount of test and calibration required by the final product. The assembly operations themselves depend largely upon manual dexterity but can be learned in a relatively short time.

2. Background or Previous Training.

There are three general types of skill required for the production of gyros: machining ability, manual dexterity, and a background in electronics. The requirement for machining is common to all types of metalworking plants. Producers of gyros, however, require machinists who can work to close tolerances, even closer in many cases than for watchmaking. In assembly, the major requirement is for manual dexterity. If a worker has manual dexterity, the actual assembly operations can be acquired through on-the-job training in a relatively short time. A background in electronics, such as that of a radio repairman, a ham operator, or the like, is valuable for the testing and trouble-shooting operations required in the production of gyros.

In the production of gyros in the US, disagreement arises not as to the types of skills required, but rather as to the best way to acquire workers with these skills. Among some gyro firms, persons such as watchmakers were deemed particularly valuable because they were familiar with handling small parts, aware of the significance of working to close tolerances, and had the dexterity and skill acquired in working with small parts. Other firms seemed to prefer going into an area in which there was a relatively large supply of potential workers, even though they were untrained in precision mechanics. These firms would depend upon selective hiring and on-the-job training to meet their demands, seeming to believe that if watchmakers and the like were hired they would have to be retrained.

In addition to the production and assembly workers previously discussed, approximately 15 percent more workers are required as production engineers, foremen, lead men, and the like. These people require considerable experience and, in some cases, engineering training.

3. Training Time.

The officials of one US company estimated that they could go into an area in which there was no experience in precision mechanics -- for example, a farming community -- and could train a labor force for a new plant (employing 100 to 200 workers) in a period of from 1 to $1\frac{1}{2}$ years. This figure assumes a cadre of 10 or 15 trained workers to use as lead men and instructors. If the cadre of trained workers were not available, the time required would be approximately 2 to 3 years.

It was estimated that in US practice, unskilled workers generally can, by definition, be trained in a few days; assembly workers require 1 to 6 month's training to become effective; test and calibration workers, 6 months to 1 year plus some background in electronics; semiskilled machinists, up to 6 months; machinists skilled on 1 machine, 6 months to 1 year; and skilled machinists, several years. Most of the direct supervisory and production engineering personnel, approximately 15 percent of the total, require considerably more than 1 year's training or experience. In many cases a degree in engineering is required.

To summarize the data given above, it appears that of the workers directly concerned with producing, assembling, and testing gyros, 10 to 20 percent require 1 year or more training, 45 to 55 percent require 6 months to 1 year, and 35 to 50 percent require less than 6 months. These estimates do not take into account the supervisory or engineering personnel who would require more than 1 year of training.

From the foregoing discussion, it appears that, in order to expand production of gyros, a country must have a relatively small number of workers to act as a cadre of foremen, lead men, calibrators, and instructors, and a limited number of machinists capable of machining to close tolerances. These workers, comprising about 25 to 35 percent of the direct labor required, could be trained over a period

of time. The training period, however, would have to be somewhat more than 1 year and, in some cases, several years. The rest of the labor required for production of gyros could be trained in 1 year or less.

D. Requirements for Floorspace.

The requirements for floorspace for the production of gyros are relatively small. An analysis of the information gathered on requirements for floorspace* indicates that 100 square feet of floorspace per worker** should be sufficient to produce most classes of gyros. The simpler classes which are produced in large numbers can be built in an area equivalent to 60 square feet per worker. It is believed that the 60 square feet per worker is about the minimum area that would be consistent with efficient production.***

The preceding discussion is based on a single-shift operation. Requirements for floorspace which are based on number of workers must be calculated in terms of the shift employing the largest number of workers. If three shifts of equal size were to be worked, the floorspace required would be somewhat more than one-third of the area required if a single shift were worked, assuming the same total production. If the total output for 3 workers on a 3-shift basis were $2\frac{1}{2}$ times that of a single worker's output on a single-shift basis -- which appears reasonable -- then 40 percent of the floorspace required for single-shift operations would be required for 3-shift operations to get the same total production.

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* For the figures underlying this discussion, see Appendix B.
** A typical US plant has facilities consisting of 5,000 workers and more than 500,000 square feet of work space, an average of 100 square feet per worker. 6/
*** In a report giving requirements for floorspace for production of aircraft instruments, 7/ it was estimated that 125 square feet are required per machine for machining operations; 70 square feet for assembly, inspection, and test area; plus 40 percent of the above total for factory services and office area. It was stated, however, that these were "comfortable" unit-space figures based on space allowances used by a US company and that these allowances might be adjusted downward without much difficulty.

E. Air-Conditioned and Dust-Controlled Area.*

The question of how much of the total production area should be air-conditioned and dust-free results in varying answers. There is a problem in distinguishing between the size of the area necessary for the accuracy and reliability of the mechanism and that desirable for the efficiency of the workers. In manufacturing to close tolerances, changes in temperature cause expansion or contraction of the material greater than the tolerance permitted. Air conditioning helps to maintain the necessary constancy of temperature. In final assembly it is important that dust in the air be reduced as much as possible because the presence of foreign matter in the completed instrument may cause failure or excessive wear. Constancy of temperature also is important in final assembly because of the close fit of certain parts. It would be possible to produce and assemble relatively imprecise gyros in plants in which only a very small percentage of the area is air-conditioned and dust-free. In the production of highly precise gyros, a somewhat greater area should be temperature-controlled and dust-free. Although it may be possible to produce gyros in areas that are not so rigorously controlled, the number of rejects, the amount of trial and error, and the possibility of failure of the instrument probably do not justify the omission of air conditioning or dust control from the point of view of economy or of reliability.

In the production of relatively precise gyros, about 40 to 50 percent of the area for producing, assembling, and testing gyros should be air-conditioned and dust-free. In the production of less precise gyros, the minimum area which must be dust-free and air-conditioned is about 10 to 20 percent of the total area.

F. Machinery and Raw Materials.

In general, there are no particular problems in acquiring machinery or raw materials for production of gyros. The requirements for machinery are relatively few, and usually for standard types. The major qualification is that the machines must be able to hold to close tolerances; they must be of the precision type. Be-

* Air conditioned means temperature and humidity controlled. Dust controlled means that measures have been taken to reduce greatly the amount of dust in the air by filtering and keeping the area under a slight pressure so that the natural air flow is outward.

cause the parts to be manufactured are relatively small in size, the machinery can be small. In addition to the machine tools and machines which are required to produce parts, balancing machines and considerable electronic or electrical test equipment is needed.

There does not seem to be any type of machinery or equipment which could cause a bottleneck in production of gyros as a result of the uniqueness of the source of supply or similar causes, although some of the electronic or electrical test equipment may be a possible exception. In the US, because it is difficult to obtain test equipment better than the highly precise gyros now being built, much of the test equipment must be built by gyro producers for their own use. The current shortage of test equipment results from the slight demand in the past for the type of equipment now required. These shortages do not apply for the gyros which are produced on a large scale.

Most of the machinery used in producing gyro parts consists of standard machine tools. In the US, two general practices are employed to get the required precision in the production of gyro parts. One method is to check the various machines being used in a plant and to select those which hold to the closest tolerances to produce the parts requiring high precision. The other method is to purchase equipment which is designed to hold to close tolerances. US producers of gyros tend to use a combination of both methods to gain the required precision in machining.

In a discussion of critical materials in the building of gyros, a distinction must be made between materials needed in the production of moderately precise gyros and those needed in the production of very high-precision gyros to be used in inertial guidance systems. In the production of gyros of moderate precision, there appear to be no really critical materials. Producers of gyros are continuously searching for better miniature precision bearings and for materials for the rotor which will not shift its center of gravity. The potentiometer wires have been suggested as a critical item of supply. Other materials suggested as critical are stainless steel, magnetic metal, cadmium, platinum alloys, shellac, aluminum, beryllium, and nickel. The amounts of these materials required are relatively small, because most of the gyros used in guided missiles weigh less than 5 pounds and the total weight of many gyros is less than 1 pound. Some gyros, however, may weigh as much as 9 or 10 pounds.

Although potentiometer wires could be a critical supply item, synchronous motors may be used as signal pick-offs instead of potentiometers. Thus, through changes in design, possible shortages in potentiometers could be avoided as a long-run problem. In the US, some gyros now use potentiometer pick-offs, and others use synchronous motors of various designs. The shift from one to the other, however, represents a major change in design which would necessitate changes in the entire gyro system.

Precision bearings are a critical item in production of gyros. Through use of floated gyros, however, the critical bearings -- that is, the gimbal bearings -- can be jeweled pivots with very little weight on them. The use of air or liquid bearings is another method of attempting to get an almost frictionless bearing. The gyros being built for the Redstone missile are of the air bearing type. This type of gyro has not been produced in quantity in the US and appears to be still in the developmental stage.

G. Time Required to Begin Production of New Models or to Expand Production.

1. To Produce First Unit, Using Production Tooling.

The time required to begin production of a new model depends largely upon the quality and completeness of the design specifications. If the design has been proved and the difficulties in production worked out in the model shop or in some other facility, the time required to begin production would be reduced to a minimum. If, on the other hand, the design is generally proved but still has to be perfected, then the time required to begin production will be increased considerably.

It is estimated that it would take approximately 6 months to begin production with a proved design that has been perfected. Tooling would take 4 or 5 months, and getting the line operating properly and the various parts produced in sufficient quantity to begin assembly would take an additional 1 or 2 months. Thus from the time the decision has been made to begin production, using production tooling, to the time the first unit has been completed, approximately 6 months may elapse, assuming that there is considerable pressure to begin production. There have been times when 1 to 1½ years have elapsed before the first unit has been produced with the use of production tooling. The greater time period resulted partly from

difficulties in tooling, but mainly from problems arising in production based on the original drawings as turned over by the design engineers. Although the design may have been proved with hand-constructed models, considerable change was necessary to set up economical production tooling. For example, a new plant was opened in an area in which there was no experience in precision mechanics. The gyro to be produced was a proved design that was in production in other plants. In this case, it took slightly more than 9 months to produce the first gyro in the new plant.

The time required to begin production, using production tooling, may be shortened somewhat if the production engineer works with the design engineer and can eliminate some of the difficulties in production in the preliminary stage. Tooling may also be anticipated, and thus tooling time may be shortened somewhat. This attempted short-cut may prove costly, however, if the design does not prove practical, and the tooling already completed must be scrapped.

2. <u>To Build Up to Scheduled Monthly Production</u>.

The total time required to reach a given level of production after the first unit is produced is in part a function of the schedule of production planned. Figure 8,* for example, indicates the estimated build-up time for 2 different gyros in 2 different typical US firms. The planned level of production was 225 gyros per month in one case and 250 gyros per month in the other. The curves are very similar in shape, with the curve for the simpler gyro being somewhat steeper. If the planned level of production had been higher, both curves would have been somewhat steeper. The higher level of production would be a function of the larger number of workers employed in the process.

Other examples of the build-up time required include the following: During World War II, a typical US firm reached a peak production of 9,000 gyros per month, 18 months after producing the first gyro, using production tooling. This particular gyro, however, was a simple air-driven rate gyro. The more complex, electric-driven gyros probably would take a somewhat longer period to reach such a high level of production. This same US firm took 1 year to reach a monthly rate of approximately 400 relatively precise electric-driven

* Following p. 24.

Month	1	2	3	4	5	6	7
Relatively Simple Vertical Gyros	15	25	50	110	160	225	—
Relatively Precise Rate Gyros	3	10	20	40	100	175	250

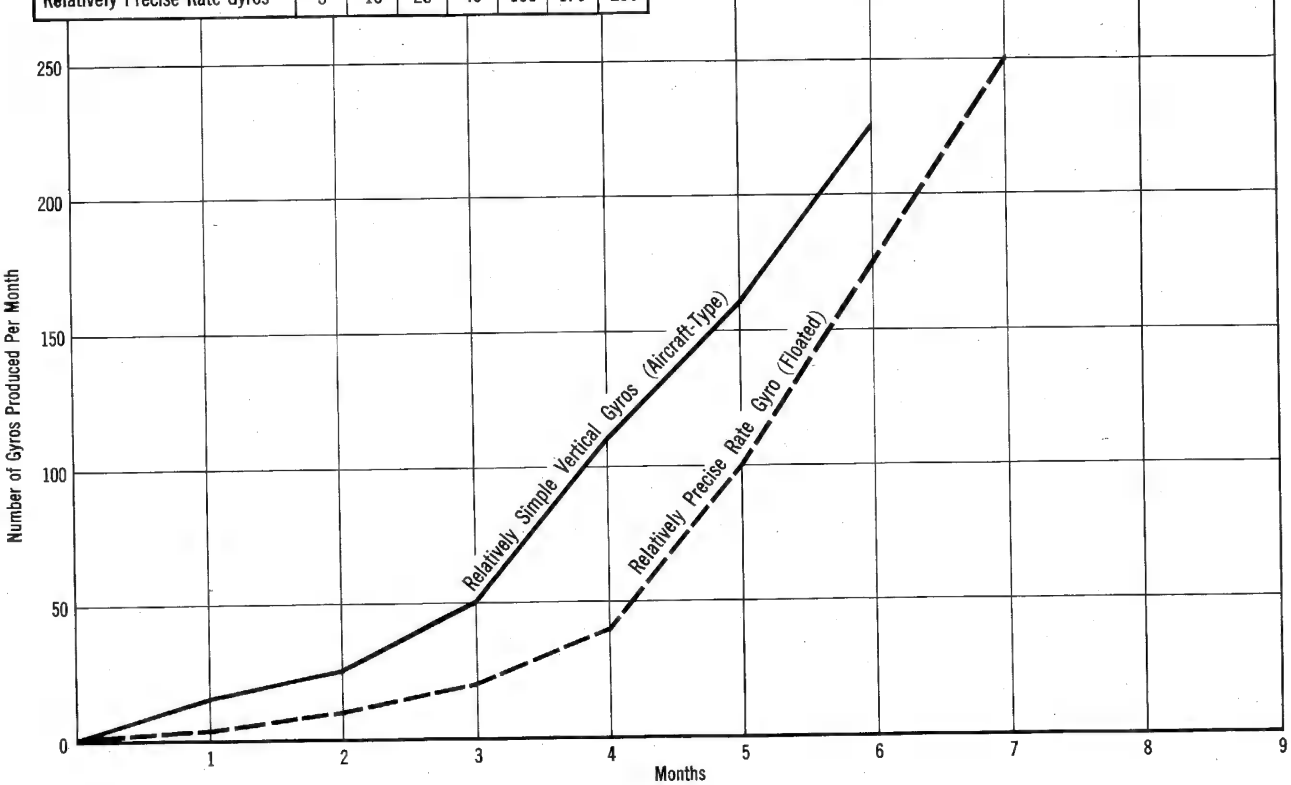

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Figure 8. Build-Up Time for Production of US Gyroscopes.

gyros of a type used in certain guided missiles. Another firm took approximately 10 months to reach a monthly peak of 500 moderately precise gyros of a type used in guided missiles.

3. To Double Production.

In the US the estimated time required to double production in an existing plant that had been producing gyros at a certain level varied from an estimate of 3 or 4 months to increase production from 400 to 800 gyros per month to an estimate of 5 to 7 months to increase production from 250 to 500 gyros per month. A third estimate was 6 months to increase production from 500 to 1,000 gyros per month.

The estimates of time required to begin production and to double production in the US are based on the labor markets in which the producing firms are located. In order to apply these data to other economies, it must be assumed that the labor market under consideration is made up of workers who -- if they do not have the same type of skills and backgrounds -- have at least a basic familiarity with production and machining and a similar aptitude or ability to learn. It appears that workers in the large industrial centers of the USSR would meet these qualifications.

III. Soviet Factors of Production.

A. General.

NIE 11-6-54 assumed a Soviet program for production of guided missiles based on estimated requirements of missiles for stockpile and for maintenance. The phasing of this program was based on estimates of the earliest time required to develop guided missiles of various types. It is therefore a possible program based on assumed rates of development and requirements rather than an actual program based on positive intelligence.

The gyros required to meet this assumed program for production are estimated below. There are, however, two major problems in an analysis of this type: (1) the type of guidance system to be used on the various Soviet guided missiles is unknown, and (2) the comparability of US and Soviet production costs and techniques as applied to gyros is uncertain.

Until more information is available, Soviet guidance systems will be assumed to be substantially similar to those being developed in the US. Even this assumption does not permit a completely firm estimate of the number and classes of gyros required. Most US guided missiles are in a developmental stage in which several guidance and control systems with varying gyro requirements are being considered. For this analysis, the guidance system requiring the most complicated gyro system has been used as the US counterpart. In the case of air-to-air missiles, two calculations based on two different guidance systems have been made.

NIE 11-6-54 uses scaled Corporals as counterparts for SSGM-1-2 and SSGM-2. Because the ground radar and Doppler system used as supervisory guidance on the Corporal does not appear to be very suitable for a guided missile with a range of several hundred miles, an inertial guidance system employing a stable platform will be assumed for these missiles.

In this section it is assumed that methods of production and therefore costs, labor, floorspace, and the like are substantially the same in the USSR as in the US. The calculations, therefore, are based on counterpart US data and are first approximations, subject to change as more positive intelligence concerning the production of gyros in the USSR becomes available. The section following will discuss some of the qualifications applying to these assumptions.

Examination of Soviet aircraft instruments indicates selection by the USSR of methods of production which emphasize rapid fabrication of parts and rapid assembly 8/ and the apparent satisfaction of the USSR with a product which may have some minor disadvantages in use if there is a gain in production. 9/ On this basis, it is assumed that types of gyros will be standardized in the USSR. Standardization of gyros allows for larger series production with attendant reductions in the cost of manufacture.

Members of the US automation team, who visited the USSR in December 1955, have reported that in machinery and machine tools the Soviet machine design and concept were equal to those in the US machine tool industry, except for perhaps 2 or 3 outstanding US companies. 10/ Moscow University was well equipped with instruments, which were apparently produced domestically. 11/ At the Experimental

and Scientific Research Institute for Metalcutting Machine Tools (ENIMS*) an automatic balancing machine for balancing the rotors of electric motors was seen. 12/

These reports, together with other reports, physical inspection, analysis of captured and purchased Soviet equipment, and analysis of new Soviet developments published in technical journals suggest that the USSR is capable of building the types of machines and instruments that are necessary for equipping gyro plants.

In view of Soviet emphasis on heavy industry in recent years, especially on the production of machine tools and similar equipment, there should be enough skilled machinists in the USSR to meet the high-priority requirements for production of gyros without undue strain on the rest of the economy. Similarly, because the USSR has been producing gyro instruments for aircraft and ships for a number of years, a limited cadre of calibrators and instructors should be available. With such a supply of labor from which trainees can be selected, a labor force to produce gyros in numbers could be brought into being within 1 year.

B. Number of Gyroscopes Required.

Table 3** indicates the number of gyros, by class, that would be required in the Soviet program for guided missiles assumed in NIE-11-6-54. The criteria for classifying the gyros were that the various gyros would serve the same general purpose and would require approximately the same degree of precision. Some of the gyros used in US counterpart guided missiles that have been grouped are admittedly dissimilar. The amount gyro used in either the Falcon or Sidewinder, for example, is an integral part of the seeker or radar and thus could not be replaced by the amount gyro used in the Nike. In fact, on the basis of present US designs, few if any of the gyros grouped are interchangeable. If standardization were adopted as a conscious policy early in the stage of design, however, many different guided missiles probably could be designed to use a single gyro. Even if standardization by the USSR were not carried out to the extent assumed, the results would still be approximately correct. In some cases, less precise gyros might be designed to meet the need, thus offsetting the somewhat higher costs associated with a lower rate of production.***

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* Eksperimental'nyy Nauchno-Issledovatel'skiy Institut Metallorezhushchikh Stankov.

** Table 3 follows on p. 29.
*** Continued on p. 31.

Table 3

Number of Gyroscopes Required for the Assumed Soviet Guided Missile Program, by Class
1954-67

Soviet Guided Missile	US Counterpart	Number of Gyros in This Class in US Counterpart	Annual Soviet Guided Missile Requirements (Units)													
			1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967
Highly precise single-degree-of-freedom gyros																
SSGM-1-1	Regulus	3			570	1,500	1,800	870	870	870	870	870	870	870	870	870
SSGM-1-2	Corporal (scaled)	3	1,350	4,050	3,150	1,050	1,050	1,050	1,050	1,050	1,050	1,050	1,050	1,050	1,050	1,050
SSGM-2	Corporal (scaled)	3					675	1,710	330	330	330	330	330	330	330	330
SAGM-2	Bomarc	3								870	2,610	4,350	6,150	6,900	1,860	1,860
ASGM-2	Rascal	3								510	1,620	600	360	360	360	360
SSGM-3	Atlas	6								600	2,400	1,320	540	540	540	540
Total			1,350	4,050	3,720	2,550	3,525	3,630	2,250	4,230	8,880	8,520	9,300	10,050	5,010	5,010
Moderately precise amount gyros																
SAGM-1	Nike	1	3,000	9,000	15,000	15,000	8,000	5,400	5,400	5,400	5,400	5,400	5,400	5,400	5,400	5,400
AAGM-1	Falcon/Sidewinder	1						13,400	40,000	61,000	20,000	20,000	20,000	20,000	20,000	20,000
Total			3,000	9,000	15,000	15,000	8,000	18,800	45,400	66,400	25,400	25,400	25,400	25,400	25,400	25,400
Moderately precise rate gyros																
Assumption 1 a/																
SSGM-1-1	Regulus	2			380	1,000	1,200	580	580	580	580	580	580	580	580	580
SAGM-1	Nike	3	9,000	27,000	45,000	45,000	24,000	16,200	16,200	16,200	16,200	16,200	16,200	16,200	16,200	16,200
SAGM-2	Bomarc	3								870	2,610	4,350	6,150	6,900	1,860	1,860
ASGM-2	Rascal	2								340	1,080	400	240	240	240	240
Total			9,000	27,000	45,380	46,000	25,200	16,780	16,780	17,990	20,470	21,530	23,170	23,920	18,880	18,880
Assumption 2 b/																
AAGM-1	Falcon	3						40,200	120,000	183,000	60,000	60,000	60,000	60,000	60,000	60,000
Total			9,000	27,000	45,380	46,000	25,200	56,980	136,780	200,990	80,470	81,530	83,170	83,920	78,880	78,880
Relatively crude amount gyros																
ASGM-1	Petrel	2	1,950	5,850	7,600	1,980	1,980	1,980	1,980	1,980	1,980	1,980	1,980	1,980	1,980	1,980

a. Assumption 1 is that the USSR will use a guidance system for its air-to-air missile requiring one amount gyro and no rate gyros, a system similar to the Sidewinder.
b. Assumption 2 is that the USSR will use a guidance system for its air-to-air missile requiring 1 amount gyro and 3 rate gyros, a system similar to the Falcon.

Two different estimates are presented for the number of moderately precise rate gyros required, based on different assumptions concerning the Soviet guidance system for air-to-air missiles. Assumption 1 is that this guidance system will be similar to the guidance system used in the Sidewinder. The Sidewinder has no rate servo feedback system and consequently requires no rate gyros. Assumption 2 is that the Soviet guidance system will resemble that of the Falcon. The Falcon uses fin position control and thus requires three rate gyros for attitude stabilization. Because of the large number of missiles contemplated in the assumed Soviet program for air-to-air missiles, the two different assumptions result in estimates which vary considerably as to the number of gyros required and consequently as to the cost of the program for guided missiles for gyros.

C. Cost and Requirements for Single-Shift Production.

Table 4* is a summary table giving the cost of manufacture, the size of the direct labor force, and the amount of floorspace required for the production of gyros for the assumed Soviet program for guided missiles, based on Assumption 1: that is, a Soviet counterpart of the Sidewinder. Table 5** is similar, except that it is based on Assumption 2: that is, a Soviet counterpart of the Falcon. Both tables are based on a single-shift production and on the time that the guided missiles are assumed to be completed.

1. Cost of Manufacture.

The costs of manufacture given in Tables 4 and 5 are the sums (obtained from Table 3***) of the number of gyros required in each class. These sums were then multiplied by the cost of each gyro (obtained from Table 1****). The unit cost used was that given in the appropriate column of Table 1 or an interpolation of the two appropriate columns -- for example, 5,000 units would represent an interpolation between the column for 500 to 1,000 units per month and that for 10,000 units per month.*****

* Table 4 follows on p. 32.
** Table 5 follows on p. 33.
*** P. 29, above.
**** P. 14, above.
***** Continued on p. 34.

Table 4

Cost of Manufacture and Requirements for Direct Labor and Floorspace for Production of Gyroscopes for the Assumed Soviet Guided Missile Program
(Based on Assumption 1 a/)
1954-67

	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967
Cost of manufacture (million 1955 US $)	8.2	21.6	31.4	28.0	18.3	24.2	40.1	57.7	34.4	34.3	35.6	36.7	29.5	29.5
Direct labor (number of workers)	700	1,800	2,650	2,400	1,550	2,000	3,250	4,700	2,750	2,750	2,850	2,900	2,400	2,400
Floorspace for production (thousand square feet)	70	180	265	240	155	200	325	470	275	275	285	290	240	240

a. Assumption 1 is that the USSR will use a guidance system for its air-to-air missile requiring one amount gyro and no rate gyros, a system similar to that of the Sidewinder. This table is phased according to the times that the guided missiles are to be produced. For a smoothed production program with a lead time, see Table 6, p. 36, below.

Table 5

Cost of Manufacture and Requirements for Direct Labor and Floorspace for Production of Gyroscopes for the Assumed Soviet Guided Missile Program
(Based on Assumption 2 a/)
1954-67

	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967
Cost of manufacture (million 1955 US $)	8.2	21.6	31.4	28.0	18.3	34.4	68.3	101.0	48.1	47.9	49.2	50.3	43.3	43.3
Direct labor (number of workers)	700	1,800	2,650	2,400	1,550	2,900	5,800	8,600	3,950	3,950	4,050	4,100	3,600	3,600
Floorspace for production (thousand square feet)	70	180	265	240	155	290	580	860	395	395	405	410	360	360

a. Assumption 2 is that the USSR will use a guidance system for its air-to-air missile requiring 1 amount gyro and 3 rate gyros, a system similar to that of the Falcon. This table is phased according to the times that the guided missiles are to be produced. For a smoothed production program with a lead time, see Table 7, p. 37, below.

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2. Direct Labor.

The number of workers required to produce gyros was calculated by summing the number of gyros of each class required (obtained from Table 3*) and the number of man-hours of direct labor required to build these classes (obtained from Table 2**) or by interpolation of Table 2 in a similar manner to that shown for Table 1.*** The total number of man-hours required was divided by 2,300**** to give the number of workers required.

3. Indirect Labor.

Tables 4 and 5***** indicate the number of persons required to perform the direct labor in production of gyros. US producers of gyros estimate, however, that the indirect labor force is from two-thirds as large to the same size as the direct labor force. The cost figures given in Tables 4 and 5 include the cost of this indirect labor, but the calculations for direct labor and for floorspace do not. The total requirements for the labor force therefore should be doubled for those classes of gyros produced in quantities of 100 units per month or less and increased by approximately two-thirds for those classes of gyros produced in quantities of 1,000 units per month or more. Because office workers and the like would be included in the indirect labor force, the addition of 60 square feet of floorspace per indirect worker should be sufficient.

4. Floorspace.

The requirements for floorspace were calculated on the basis of an average of 100 square feet of floorspace per worker, which appears to be approximately the ratio used in the US for similar types of plants. As discussed in the section on US requirements for floorspace,† this figure could be cut as much as 40 percent to allow only 60 square feet per worker.

* P. 29, above.
** P. 16, above.
*** See III, C, p. 31, above.
**** The standard work week in the USSR is now 46 man-hours. Allowing 2 weeks for holidays and vacations would give 50 times 46 or 2,300 man-hours per year.
***** Pp. 32 and 33, respectively, above.
† See II, D, p. 20, above.

D. Cost and Requirements for Three-Shift Production.

Three-shift production is not as efficient as single-shift production. The probable maximum output of 3-shift production is about $2\frac{1}{2}$ times the output of a single shift, inasmuch as time must be allowed for repair, cleaning, and similar services. Therefore, to produce the same amount of goods on a 3-shift basis as on 3 single shifts, the total labor force will have to be increased approximately 20 percent. If this larger total labor force were to be divided into 3 shifts of equal size, the total requirements for floorspace would be 40 percent of the floorspace requirements of a single shift. The effect on the cost of manufacture is not known. This cost, however, is likely to increase somewhat. The larger labor force causes an increase in labor costs. The lower requirements for floorspace and also for machinery result in a decrease in overhead costs. The lower overhead costs offset to some extent, but probably not entirely, the higher labor costs.

E. Introduction of Lead Time and Smoothing of Production.

Tables 6 and 7* were calculated from Tables 4 and 5** by the introduction of a production lead time and by smoothing the peaks in production. The basic assumptions which entered into the calculation of Tables 6 and 7 were: (1) the gyros would be produced approximately 1 year ahead of the time the missiles were to be available and (2) production of gyros would be scheduled ahead so that no extreme fluctuations would be necessary. On the basis of the second assumption, some excess production of gyros might occur during 1957-59. The production of gyros in 1960, however, would not be quite equal to the number of gyros required by the missiles to be made available during 1961. The production lead time would be cut to approximately 6 months. By 1962 a production lead time of approximately 1 year would be regained. The requirements for direct labor were used as the basis for the smoothing of production in Tables 6 and 7. The cost of manufacture was calculated from the figures for direct labor on the basis of $12,000 per man-year.***

* Tables 6 and 7 follow on pp. 36 and 37, respectively.
** Pp. 32 and 33, respectively, above.
*** The average cost of manufacture per man-year calculated from Tables 4 and 5 is $12,000. The range is from $11,666 to $12,655.
(Text continued on p. 38.)

Table 6

Smoothed Cost of Manufacture and Requirements for Direct Labor and Floorspace for Production of Gyroscopes for the Assumed Soviet Guided Missile Program
(Based on Assumption 1 a/)
1953-66

	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
Cost of manufacture (million 1955 US $)	8.4	21.6	31.2	31.2	31.2	31.2	33.6	36.0	36.0	36.0	33.6	33.6	28.8	28.8
Direct labor (number of workers)	700	1,800	2,600	2,600	2,600	2,600	2,800	3,000	3,000	3,000	2,800	2,800	2,400	2,400
Floorspace for production (thousand square feet)	70	180	260	260	260	260	280	300	300	300	280	280	240	240

a. Assumption 1 is that the USSR will use a guidance system for its air-to-air missile requiring one amount gyro and no rate gyros, a system similar to that of the Sidewinder. This table is phased according to the times that the gyros are to be produced. The assumed Soviet aim is to have a 1-year lead for production of gyros. In addition, this table anticipates peak requirements and the prior production and stockpiling of gyros to eliminate extreme fluctuation in production of gyros and in facilities.

Table 7

Smoothed Cost of Manufacture and Requirements for Direct Labor and Floorspace for Production of Gyroscopes for the Assumed Soviet Guided Missile Program
(Based on Assumption 2 a/)
1953-66

	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
Cost of manufacture (million 1955 US $)	8.4	21.6	31.2	33.6	36.0	42.0	60.0	60.0	60.0	60.0	48.0	48.0	48.0	43.2
Direct labor (number of workers)	700	1,800	2,600	2,800	3,000	3,500	5,000	5,000	5,000	5,000	4,000	4,000	4,000	3,600
Floorspace for production (thousand square feet)	70	180	260	280	300	350	500	500	500	500	400	400	400	360

a. Assumption 2 is that the USSR will use a guidance system for its air-to-air missile requiring 1 amount gyro and 3 rate gyros, a system similar to that of the Falcon. This table is phased according to the times that the gyros are to be produced. The assumed Soviet aim is to have a 1-year lead for production of gyros. In addition, this table anticipates peak requirements and the prior production and stockpiling of gyros to eliminate extreme fluctuation in production of gyros and in facilities.

F. Maximum Annual Cost and Requirements.

On the assumption that the USSR would use a relatively simple guidance system in its air-to-air missile, thus requiring only 1 gyro per missile, Table 6* indicates that the maximum annual cost of manufacture would be $36 million, the number of workers engaged in direct labor would be 3,000, and the floorspace required for production would be 300,000 square feet. According to Table 4,** the maximum annual cost of manufacture would be approximately $58 million, the number of workers engaged in direct labor would be 4,700, and the floorspace required for production would be 470,000 square feet. Table 4 has been constructed on the assumption that the gyros would be turned out at the time needed with no advance production for the purpose of smoothing peaks in production. Table 6 has been constructed on the assumption that production would be leveled and that some gyros would be produced in anticipation of peak needs. Because of incomplete foresight on the part of planners and possibly because of changes in design, actual requirements for production probably would fall somewhere between the amounts indicated in Tables 4 and 6. Some allowance would have to be made for indirect labor and for floorspace to accommodate the indirect labor. A conservative estimate would place the maximum annual cost of production of gyros at $50 million, total labor (including indirect) at 8,000 workers, and floorspace at 640,000 square feet.***. It will be noted that all these calculations are for single-shift operations. The floorspace requirements could be reduced by more than half on a multiple-shift basis, but labor would have to be increased, and costs of manufacture probably would rise.

On the assumption that the USSR would adopt the more complicated guidance system for its air-to-air missile, it is conservatively estimated**** that the maximum annual cost of manufacturing gyros would be $85 million; total labor (including indirect), 14,000 workers; and total floorspace, 1.12 million square feet.

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* P. 36, above.

** P. 32, above.

*** Indirect labor was calculated as equal to direct labor -- 4,000 workers -- and floorspace was calculated as 100 square feet per direct worker and 60 square feet per indirect worker.

**** This estimate is an interpolation of Tables 5 and 7, pp. 33 and 37, respectively, above, calculated by the same method as the estimate discussed earlier in this section.

G. Effect of Stable Platform, or Stable Element, Costs.

Tables 4, 5, 6, and 7* are all based on production of gyros. The highly precise gyros for navigation, however, are used on stable platforms, or stable elements. If calculations regarding cost of manufacture and requirements for direct labor and floorspace were based on the cost of the stable platforms rather than on the cost of the gyros going into the platform, $12.5 million, 1,500 workers, and 120,000 square feet of floorspace would have to be added to the conservative estimates given in F, above.**

H. Conclusions.

If the USSR were using a more complicated guidance system for its air-to-air missile (comparable to that of the Falcon) and if -- for missiles which include a stable platform -- the costs, direct labor, and floorspace factors applying to the stable platform were used, conservative estimates based on a single shift would be as follows: maximum annual cost of manufacture -- $97.5 million; total labor (including indirect) -- 15,500 workers; and total floorspace -- 1.24 million square feet. On the basis of the more likely assumption that a simple guidance system similar to that of the Sidewinder is to be used, the maximum annual cost of manufacture is approximately $62.5 million, and 9,500 workers and 760,000 square feet of floorspace are required. It is apparent from the preceding estimates that, because of the large numbers of missiles involved, the cost of manufacture and the labor required for moderately precise gyros considerably outweigh the cost of manufacture and the labor required for the stable platforms. For example, the assumption that the air-to-air missile will include 3 moderately precise rate gyros rather than no rate gyros adds some $35 million and 6,000 workers to the annual maximum requirements. If the entire stable platform rather than the gyros alone were included in the assumption, approximately $12.5 million and 1,500 workers would have to be added to the estimate.

Because the preceding estimates are the maximum annual amounts, in most years the cost of manufacture will be less than $40 million, the requirements for labor less than 6,000 workers, and the floorspace

* Pp. 32, 33, 36, and 37, respectively, above.
** The maximum additional cost of manufacture would be $15.8 million, and the maximum additional direct labor required would be 870 workers.

requirements less than 500,000 square feet. It does not appear, therefore, that the gyros, in particular, and the precision mechanisms, in general, required for the assumed program for guided missiles will cause an undue burden on the economy of the USSR. The current status of the gyro and precision mechanisms industries in the USSR, however, is unknown, and thus the effect of the assumed program for guided missiles on the specific industries cannot be precisely evaluated. As previously noted, inasmuch as approximately 65 to 75 percent of the workers required in the gyro industry can be trained in 1 year or less, the Soviet gyro program should require approximately 2,000 workers who are highly skilled -- who need more than 1 year's training. On the assumption that the nucleus of skilled labor is available, there is no apparent reason why the gyro industry cannot be expanded to meet requirements which may be levied upon it if it is not already of sufficient size. The requirements of the gyro industry likewise should not place an undue burden upon the precision mechanisms industry in the USSR.

I. Gyroscopes for the Soviet Aircraft Industry.

The annual cost of producing gyros for aircraft in the USSR is estimated to be approximately $24 million, the total number of workers required to produce these gyros is approximately 3,000, and the total floorspace required is approximately 250,000 square feet.

If the requirements for the production of gyros for aircraft are added to the requirements for the production of gyros for guided missiles on a single-shift basis, a conservative estimate of the range of the maximum annual requirements for production of all gyros in the USSR would be as follows: manufacturing cost, $86.5 million and $121.5 million; total labor (including indirect), 12,500 and 18,500 workers; floorspace, 1 million and 1.5 million square feet.

The additional amounts, both in dollars and labor, indicated by the requirements of aircraft for gyros, added to the requirements of guided missiles for gyros, would not be of sufficient magnitude to change the conclusions reached in H, above.

IV. Qualifications on the Application of US Factors of Production to the USSR.

The methodology used in III, above, in determining the cost of manufacture and the requirements for labor and floorspace in the

production of gyros for a possible guided missile program in the USSR, based on US analogy, has many disadvantages and opportunities for error. In the first place, the US factors used may not be entirely accurate. This is especially true for those items which have not yet been produced in volume. The US factors, however, are based on the best US estimates available. On the assumption that the US factors do accurately reflect the US cost of manufacture, there are, nevertheless, a number of qualifications which must be considered in judging the probable accuracy of the results of using US analogy in determining Soviet requirements. In this section some of the assumptions implicit in applying US data to Soviet industry will be enumerated, discussed, and qualified.

A. Assumption That the Product Is Comparable.

Although in the estimates given above it was assumed that the gyros used in various Soviet guided missiles would be comparable to the gyros used in the US counterparts, there are at least three points which should be considered in evaluating this assumption. First, the quantity and quality, or class of gyros, used in a guided missile are partly a function of the type of guidance system used -- inertial, star-supervised, ground radio, beam-riding, homing, or other type of guidance. The type or types of guidance used or to be used in Soviet guided missile programs are not known at this time. Second, the class of gyro required is partly a function of the accuracy required of the guided missile. Here again, the Soviet philosophy as to the accuracy required of Soviet guided missiles is unknown. Third, even though the USSR requires the same accuracy for Soviet gyros as the US does for US gyros, different specifications and tolerances may be levied on the producer. For example, standards of service life, ease of maintenance, finish, appearance, and similar characteristics may be lower in the USSR than in the US.

It is apparent from the examination of various Soviet aircraft instruments that the USSR has redesigned many US or European instruments in such a way that they are adequate for the task intended and also cheaper to produce. In some respects the Soviet design may be somewhat inferior to that of the instrument from which it was adapted, but the Soviet instruments are essentially equal to their foreign predecessors in sensitivity and ruggedness.*

* For a fuller discussion of this point, see Appendix A.

The Soviet aircraft instruments mentioned above are relatively simple instruments and cannot be considered equivalent to the classes of gyros discussed in connection with guided missiles. Soviet designers, however, are ingenious in simplifying designs to reduce the cost of manufacture. There is no reason to believe that this simplification of design will not be attempted in the more complicated instruments. The extent of Soviet success, however, cannot be judged at this time.

B. Assumption That the Methods of Production Are Comparable.

Examination of Soviet aircraft instruments indicates that the latest Soviet techniques and methods can be considered comparable to those used in the US. The Soviet instruments examined revealed that two basic methods of production had been used. Under the first method a low production type of job shop, equipped with universal machine tools, was apparently used to produce an early class of gyro. The second method is illustrated by an instrument produced in 1951. This instrument was designed for high-production tooling and large-scale serial production and utilizes many of the features and advantages of mass production such as universal machine tools, low skills, and line-production layout. 13/

At the present stage of development in the field of more precise gyros in the US, both of the methods mentioned above are used. The job-shop type of production is used for small lots or for developmental and perfecting runs. When designs have been perfected, universal machine tools and line-production layout may be used. Assembly is still a bench-type operation. As production increases in quantity, more use is made of jigs and fixtures, but at the present time US producers make little use of truly specialized machines and true production-line assembly techniques in production of gyros. The cost of manufacture in the US may be reduced considerably by standardizing classes of gyros used so that larger scale production could be achieved. The cost of production given in Table 1* and the labor requirements given in Table 2,** however, have been estimated on the basis of varying quantities of production. Thus the scale of production has been taken into account in the estimates of cost.

* P. 14, above.
** P. 16, above.

C. Assumption That the Productivity of Labor Is Comparable.

The application of US factors of production to Soviet requirements in a given field implies that the productivity of labor in the two countries is equal. For industry in general there seems to be little doubt that this assumption is false. In intelligence reports which attempt to compare the productivity of the US and the USSR, 14/ the productivity of labor in various industries in the USSR appears to be 2/3 to 1/2 or less that of the US. Among Soviet goals is an increase in the productivity of labor between 1956 and 1960:

> In industry: not less than by 50 percent, which must principally be realized through the growth of the technical equipment of labor and through the introduction of advanced technical equipment and technology, the all-around expansion of complex mechanization and automation of production processes, the modernization of the equipment, the wide-scale expansion of the specialization of enterprises, and the introduction on this basis of mass methods of production, a radical improvement of labor organization and the liquidation of wastage of working time, as well as the reduction of labor consumed in auxiliary operations. 15/

There are several factors which affect the productivity of labor in industry, including the quantity and quality of the capital equipment used; the organization of production, both in the entire economy and in the individual enterprise; and the diligence and skill of labor in the industry. As indicated in the quotation given above, the USSR intends to increase productivity in industry in general by at least 50 percent in the next 5 years by improving these factors.

Reports of the trip by the US automation team to the USSR 16/ indicate that in most of the plants visited much of the equipment was old, production often was not well planned, materials-handling equipment was not widely used, and poor plant layout caused waste motion. The same team reported, however, that the workers were working harder than in US plants, that the number of technical workers in Soviet plants was impressive, that the machine design and concept of many machine tools seemed equal to those of the US machine tool industry except for perhaps 2 or 3 outstanding US companies, that the laboratories in Moscow University and ENIMS were well equipped with domestically produced instruments, and that the tools were well maintained and doing a good job.

In an industry such as that producing precision gyros for guided missiles, the high priority of the guided missile program can be expected to attract (or draft) some of the best workers, machinery, and managers. Although productivity in this particular industry may not equal that in the US, it is likely that the difference would be considerably less than indicated by general indexes.

D. Lead Time in the Soviet Aircraft Industry.

A recent article in an intelligence journal 17/ indicated that production lead times in production of aircraft in the USSR are being compressed. Among the factors compressing lead time are the following:

1. The Council of Ministers may waive state trials and may order immediate production.

2. Plant managers and design chiefs may speed the developmental cycle by pretooling.

3. The Soviet industrial philosophy calls for a constant high rate of production of relatively few basic models, constant full employment, tight control of the industrial labor force, and stability of the engineer population.

4. There is a great degree of standardization in materials and accessories.

5. Where possible, new aircraft designs minimize the need for radical departures from previous production techniques, tools, and jigs.

6. There is a high degree of coordination and unity of effort in seeing that component parts are delivered on schedule.

Although the evidence submitted in the article cited above indicates that at least one model of a Soviet aircraft was produced in less time than a similar US type from requirement stage to production of the first unit, the evidence is still inconclusive as to the extent that this example can be generalized.

If the amount of effort and degree of priority being placed on a certain type of aircraft in both the US and the USSR are considered, the comparison of production lead times becomes extremely difficult and tenuous. There probably would not be a great deal of difference in lead times if both countries were working with the same degree of concentration on a given project.

Although the foregoing discussion of lead time in the USSR applies to the aircraft industry, the gyro industry should face somewhat similar problems and should receive somewhat similar priorities. The technical problems faced both in the US and in the USSR should be similar. The production lead times given for US gyro plants* are based on the assumption of wartime pressure to produce and should be indicative of the lead times required in the USSR under the same circumstances.

E. Recapitulation.

The use of US counterpart information as a basis for determining Soviet requirements for gyros for guided missiles and for estimating the cost of manufacture of gyros to the USSR, both in terms of dollars and of labor, is at best a rough first approximation. The errors that may result from the assumptions made when using US analogy, however, tend to be offsetting. As indicated previously, examination of Soviet aviation instruments indicates simplification of design over counterpart US instruments with little, if any, loss in functional ability. These simplifications aimed at increasing producibility may well offset the apparently lower productivity of labor. Until more definite information on the actual differences in US and Soviet factors can be determined, calculations using US factors of production probably will be the most indicative of the scale of effort required in the production of gyros to support the assumed Soviet program for guided missiles.

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* See II, G, p. 23, above.

APPENDIX A

COMPARABILITY OF SOVIET AND US AIRCRAFT INSTRUMENTS

A recent intelligence report based on a study of several Soviet aircraft instruments indicates that those of mechanical and electromechanical types that are patterned after foreign instruments are simpler in design and are more crude in workmanship. The Soviet instruments are essentially equal to their foreign predecessors in sensitivity and ruggedness, although they have a shorter life expectancy. 18/ The report also noted that few fully machined parts were found. Machining operations on stampings and castings were numerous but appeared to have been done only where necessary. Gaskets were used to compensate for the generally poor finishes in order to meet the functional requirements of the instrument. The report concluded that the use of gaskets may have lowered the cost of manufacture considerably. 19/ Loose tolerances in the stampings and machined parts did not appear to prevent the construction of a reasonably accurate instrument. 20/

A report based on the analysis of a Soviet gyro-optical sight stated that workmanship on the motor and gyro assembly is about equal to that on the equivalent US sight. The gyro wheel was excellently made. In general, the Soviet range potentiometer unit is somewhat crude in appearance, but it is well made and probably will give more trouble-free service than the potentiometer used on the US K-14. In some respects the construction of the Soviet optical sight is inferior to the US sight. Fungus- and corrosion-resistant coatings are not used. Machine operations are held to a minimum. With the exception of the critical optical and gyro components, the techniques for production are designed to require only semiskilled labor. The cost of manufacturing the Soviet sight in the US would be approximately 75 percent of the cost of manufacturing the US sight. 21/

The following quotation seems to summarize the situation as to the adequacy of Soviet aircraft instruments:

> The MIG-15 instruments are generally designed for operational adequacy and low production costs. In the case of the attitude gyro there has been some sacrifice in performance caused by the method of gimbaling. This sacrifice is apparently accepted

> in order to permit a reduction in manufacturing costs. The operational effect of this drop in performance may be reduced to insignificance by pilot adaption to minor inaccuracies in presentation. 22/

There is evidence that the USSR is striving for simplification of design in guided missiles. [redacted]

25X1X6

APPENDIX B

METHODOLOGY

1. General.

The calculations in this report are based on information obtained from the US gyro program. The various gyros for which information on cost and labor were received are identified in Tables 8 and 9,* by consecutive numerals. The grouping of the gyros is based on the class of gyro, the degree of precision, and the use for which the gyro is intended. Some of the gyros listed were not developed specifically for guided missiles, but are suitable for use in certain guided missiles.

2. Cost of Production per Unit.

Table 1** in the text is a summary of the information presented in Table 8. Table 8 presents US costs of production per unit for various classes of gyros and stable platforms. For each class of gyro a typical cost of manufacture was derived. For the classes and levels of production for which sufficient data were available, the typical cost is an arithmetic mean, modified by known differences in precision or other physical characteristics and by apparent biases in estimates as revealed by an analysis of all the data available. The typical cost of manufacturing 50 units per month was estimated as 150 percent of the cost of manufacturing 100 to 200 gyros per month. The figure of 150 percent was derived from the few instances in which the cost of manufacturing 50 units per month was given and from a few examples of the cost of manufacturing 10 units per month.

The cost of manufacturing relatively crude amount gyros for stabilization is assumed to have approximately the same relationship to the cost of manufacturing relatively crude rate gyros for stabilization as the cost of moderately precise amount gyros has to that of moderately precise rate gyros. The cost of relatively crude amount gyros, therefore, is derived by multiplying the cost of relatively crude rate gyros by $2\frac{1}{2}$.

* Tables 8 and 9 follow on pp. 51 and 54, respectively.
** P. 14, above.

3. Direct Labor per Unit.

Table 2* in the text is a summary of the information presented in Table 9.** Table 9, which relates to the US requirements for direct labor per unit of production, refers to the same gyros presented in Table 8,*** and the methodology is the same. Analysis of the data submitted for certain gyros revealed that there was evidently considerable purchase of parts or subassemblies and that therefore the direct labor required was understated. This factor was given consideration in arriving at the typical requirements for direct labor.

4. Floorspace Required per Worker.

The estimates of total floorspace required per worker in the US are based on the information summarized in Table 10.****

In the calculations of floorspace required in the USSR, estimates of 100 square feet per worker engaged in direct labor and of 60 square feet per worker engaged in indirect labor were used.

5. Stable Platforms.

The stable platforms for which factors of production are presented are not suitable for the intermediate- and long-range ballistic missiles. Therefore, in making calculations of the cost of manufacture and of the requirements for labor based on the use of stable platforms, the SSGM-3 (Atlas) was given a factor of 3, the SSGM-2 (Scaled Corporal) was given a factor of 2, and all other guided missiles requiring platforms were given a factor of 1. The platform for the ICBM is assumed, therefore, to cost 3 times as much and to take 3 times as long to build as the platforms for which information was obtained. These costs apply to models for manufacture and not to the developmental models, which are necessary before production-line techniques are possible.*****

* P. 16, above.
** Table 9 follows on p. 54.
*** Table 8 follows on p. 51.
**** Table 10 follows on p. 57.
***** Continued on p. 59.

Table 8

US Cost of Manufacture per Unit for Various Classes of Gyroscopes and for Stable Platforms at Various Rates of Production

1955 US $

Class of Gyro	50 Units per Month	100 to 200 Units per Month	500 to 1,000 Units per Month	10,000 Units per Month
Highly precise single-degree-of-freedom gyros for navigation				
Number 1	2,225	1,430	960	N.A.
Number 2	N.A.	1,325	1,200	900
Number 3	N.A.	1,250	1,100	850
Typical cost of manufacture	2,000	1,335	1,150	900
Relatively precise amount gyros				
Number 4	N.A.	1,500	1,250	950
Typical cost of manufacture	2,250	1,500	1,250	950
Relatively precise rate gyros				
Number 5	1,160	730	535	N.A.
Number 6	N.A.	1,240 a/*	450	373 b/
Typical cost of manufacture	1,050	700	500	400

* Footnotes for Table 8 follow on p. 53.

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Table 8

US Cost of Manufacture per Unit for Various Classes of Gyroscopes and for Stable Platforms at Various Rates of Production
(Continued)

1955 US $

Class of Gyro	50 Units per Month	100 to 200 Units per Month	500 to 1,000 Units per Month	10,000 Units per Month
Moderately precise amount gyros				
Number 7	N.A.	1,000	800	N.A.
Number 8 c/	3,705	1,480	950	N.A.
Number 9	N.A.	815	625	500
Number 10	N.A.	850	640	480
Number 11	N.A.	950	675	575
Typical cost of manufacture	1,425	950	750	600
Moderately precise rate gyros				
Number 12	N.A.	300	260	N.A.
Number 13	N.A.	410	322	240
Typical cost of manufacture	525	350	290	240
Relatively crude rate gyros				
Number 14	335	200	125	N.A.
Typical cost of manufacture	300	200	150	125

Table 8

US Cost of Manufacture per Unit for Various Classes of Gyroscopes and for Stable Platforms
at Various Rates of Production
(Continued)

1955 US $

Class of Gyro	50 Units per Month	100 to 200 Units per Month	500 to 1,000 Units per Month	10,000 Units per Month
Three-gyro platforms				
Number 15	N.A.	7,500	5,700	4,500
Number 16	N.A.	8,720	N.A.	N.A.
Typical cost of manufacture	11,250	7,500	5,700	4,500

a. This figure appears excessive for this quantity. If the output was considered to be 10 units per month, this figure would be more comparable to the other figures.
b. For 2,000 units per month.
c. This gyro is somewhat more precise than the other gyros in this class. It falls between this class and the relatively precise amount gyros.

Table 9

US Requirements for Direct Labor per Unit for Various Classes of Gyroscopes and for Stable Platforms at Various Rates of Production

Man-Hours

Class of Gyro	50 Units per Month	100 to 200 Units per Month	500 to 1,000 Units per Month	10,000 Units per Month
Highly precise single-degree-of-freedom gyros for navigation				
Number 1	384	214	122	N.A.
Number 2	N.A.	235	190	145
Number 3	N.A.	225	185	140
Typical direct labor	335	225	185	140
Relatively precise amount gyros				
Number 4	N.A.	230	185	140
Typical direct labor	345	230	185	140
Relatively precise rate gyros				
Number 5	183	89	46	N.A.
Number 6	N.A.	311 a/*	105	94
Typical direct labor	180	125	95	80

* Footnotes for Table 9 follow on p. 56.

Table 9

US Requirements for Direct Labor per Unit for Various Classes of Gyroscopes and for Stable Platforms at Various Rates of Production
(Continued)

Man-Hours

Class of Gyro	50 Units per Month	100 to 200 Units per Month	500 to 1,000 Units per Month	10,000 Units per Month
Moderately precise amount gyros				
Number 7	N.A.	225	180	N.A.
Number 8 b/	632	253	141	N.A.
Number 9	N.A.	162	115	90
Number 10	N.A.	155	110	82
Number 11	N.A.	167	120	95
Typical direct labor	285	190	140	110
Moderately precise rate gyros				
Number 12	N.A.	75	60	N.A.
Number 13	N.A.	87	68	55
Typical direct labor	120	80	65	50
Relatively crude rate gyros				
Number 14	58	31	15	N.A.
Typical direct labor	50	35	25	20

Table 9

US Requirements for Direct Labor per Unit for Various Classes of Gyroscopes and for Stable Platforms at Various Rates of Production
(Continued)

Man-Hours

Class of Gyro	50 Units per Month	100 to 200 Units per Month	500 to 1,000 Units per Month	10,000 Units per Month
Three-gyro platforms				
Number 15	N.A.	1,050	775	625
Number 16	N.A.	1,088	N.A.	N.A.
Typical direct labor	1,575	1,050	775	625

a. This figure appears excessive for this quantity. If the output was considered to be 10 units per month, this figure would be more comparable to the other figures.
b. This gyro is somewhat more precise than the other gyros in this class. It falls between this class and the relatively precise amount gyros.

Table 10

Average Floorspace Required per Worker in Production of Gyroscopes in Four Typical US Companies a/*
1955

Square Feet

Company	Remarks	Production	Assembly	Total
A	Rate of production of 100 units per month or less			100
	Rate of production of more than 100 units per month			80
B	Relatively simple gyro	100	30	65 b/
	Gyro of average complexity	100	40	70 b/
	Complicated, highly precise gyro	100	80	90 b/
C	Gyro of average complexity at a rather high rate of production			60
D	At production rates of 100 to 200 units per month			
	(1) Attitude gyro of average complexity			115
	(2) Simple rate gyro			75
	(3) Combination of (1) and (2), above			90

* Footnotes for Table 10 follow on p. 58.

Table 10

Average Floorspace Required per Worker in Production of Gyroscopes
in Four Typical US Companies
1955
(Continued)

Square Feet

Company	Remarks	Production	Assembly	Total
D (Continued)	At production rates of 500 units per month			
	(1) Attitude gyro of average complexity			90
	(2) Simple rate gyro			60
	(3) Combination of (1) and (2), above			75

a. The figures in this table may not be entirely comparable. The figures for Company A are average requirements for floorspace to be applied to both direct and indirect labor. The figures for Company B presumably do not include space for such common facilities as washrooms, cafeterias, and similar services and do not make allowance for large- or small-scale production. The figures for Company D are calculations based on total floorspace required and thus should include all the ancillary services.
b. The total is for direct labor, calculated on the basis of 50 percent production and 50 percent assembly, which is close to the breakdown for figures on gyro personnel of the company.

6. Cost of Manufacture and Requirements for Labor for Aircraft Gyros.

The US Air Force estimates of the number of aircraft produced in the USSR in 1955 by types 24/ were rounded and used as the basis for the quantities of gyros required. From other US Air Force reports, 25/ some of the gyro instruments used in Soviet aircraft were determined. This information, together with US practice, was used to fit requirements for aircraft gyros into the system of classification used in this report.

The following data or assumptions were used:

a. Fighters use the following three gyro instruments:

(1) AGK-47b, a combined artificial horizon and turn and bank indicator, equivalent to a relatively crude amount gyro.

(2) PDMK-3, a remote indicating compass which includes a DGMK-3 directional gyro unit, equivalent to a relatively crude amount gyro.

(3) NS-23, a computing sight which includes a rate gyro, equivalent to a relatively crude rate gyro.

b. All-weather fighters are assumed to require the equivalent of one relatively precise amount gyro for radar stabilization.

c. Trainers are assumed to use the same instruments as fighters, excluding the sight. Two-thirds of the trainers are assumed to require dual instruments.

d. Transport aircraft are assumed to have dual sets of instruments similar to fighters and an autopilot which would require the equivalent of two relatively crude amount gyros.

e. Commercial/utility aircraft are assumed to have one set of flight instruments similar to fighters.

f. All bombers are assumed to have dual controls and autopilots. There is a requirement, therefore, for the equivalent of six relatively crude amount gyros.

(1) Light bombers are assumed to require, in addition, 2 relatively precise amount gyros -- 1 for bombsight purposes and 1 for fire-control purposes.

(2) Medium and heavy bombers are assumed to require 1 stable platform system for blind bombing purposes and 1 relatively precise amount gyro for fire-control stabilization, in addition to the flight instruments indicated above for bombers in general.

g. It is assumed that an additional 20 percent of each class of gyro will be required for spares.

Table 11* indicates the number of gyros required for Soviet aircraft, by class of gyro.

Soviet cost of manufacture was calculated on the basis of the information in Tables 1** and 11. The values used from Table 1 were obtained by interpolation of the proper columns. Thus:

Number	Class	Cost per Unit	Total
5,000	Relatively crude rate gyros	$ 175	$ 875,000
33,000	Relatively crude amount gyros	350	11,550,000
4,000	Relatively precise amount gyros	1,375	5,500,000
600	Stable platforms	10,000***	6,000,000
	Total		$23,925,000

Soviet requirements for direct labor were calculated from Tables 2**** and 11 in the same manner as the cost of manufacture was calculated. Thus:

* Table 11 follows on p. 62.
** P. 14, above.
*** This platform is assumed to be somewhat simpler than the platform given in Table 1, p. 14, above.
**** P. 16, above.

Number	Class	Man-Hours per Unit	Total
5,000	Relatively crude rate gyros	30	150,000
33,000	Relatively crude amount gyros	50	1,650,000
4,000	Relatively precise amount gyros	205	820,000
600	Stable platforms	1,500*	900,000
	Total		3,520,000

On the basis of each person working 2,300 man-hours per year, to obtain the above figure for total direct labor would require 1,520 workers. On the basis of an equivalent number of man-hours for indirect labor, a total of approximately 3,000 workers would be required to produce gyros for aircraft in the USSR.

* This platform is assumed to be somewhat simpler than the platform given in Table 2, p. 16, above.

Table 11

Soviet Requirements for Gyroscopes for Aircraft, by Class

(1) Class of Gyro	(2) Type of Aircraft	(3) Number of Gyros Each	(4) Number of Aircraft Produced	(5) Number of Gyros for Production a/	(6) Spares b/	(7) Total c/
Relatively crude rate gyros	Fighter	1	4,000	4,000	800	5,000
Relatively crude amount gyros	Fighter	2	4,000	8,000	1,600	
	Trainer	4	1,000	4,000	800	
	Trainer	2	500	1,000	200	
	Transport	6	600	3,600	720	
	Commercial/utility	2	500	1,000	200	
	Bomber	6	1,700	10,200	2,040	
Total				27,800	5,560	33,000
Relatively precise amount gyros for fire control	Fighter	1	600	600	120	
	Light bomber	2	1,200	2,400	480	
	Medium and heavy bombers	1	500	500	100	
Total				3,500	700	4,000
Stable platforms	Medium and heavy bombers	1	500	500	100	600

a. Column 3 times column 4.
b. Twenty percent of column 5.
c. Rounded.

APPENDIX C

GAPS IN INTELLIGENCE

Little is known about the precision machine industry, in general, or the precision gyro industry, in particular, in the USSR. The location of several plants producing gyro aircraft instruments or marine gyro compasses is known, and some of these instruments have been examined. Information relating to these plants is slight, however, and information concerning the development and production in the USSR of the more precise types of gyros necessary for a guided missile program is almost nonexistent. Any information concerning Soviet production of gyros suitable for guided missiles will be useful in filling this major gap in intelligence.

Within the framework of this report, the major gap is information concerning the cost of manufacture and the labor required to produce the highly precise gyros and stable platforms used in medium- and long-range ballistic missiles. This gap is largely a result of the lack of experience in US production of this class of gyro or platform. Further collection, which is being undertaken, should aid in filling this gap in the near future.

APPENDIX D

SOURCE REFERENCES

This report is based largely on information received from US producers of gyros. Therefore, much of the material is not specifically documented.

The majority of the sources referred to are completed intelligence reports, technical reports published by producers of gyros, or reports published by missile contractors. All sources are evaluated RR 2 unless otherwise indicated.

Evaluations, following the classification entry and designated "Eval.," have the following significance:

Source of Information	Information
Doc. - Documentary	1 - Confirmed by other sources
A - Completely reliable	2 - Probably true
B - Usually reliable	3 - Possibly true
C - Fairly reliable	4 - Doubtful
D - Not usually reliable	5 - Probably false
E - Not reliable	6 - Cannot be judged
F - Cannot be judged	

"Documentary" refers to original documents of foreign governments and organizations; copies or translations of such documents by a staff officer; or information extracted from such documents by a staff officer, all of which may carry the field evaluation "Documentary."

Evaluations not otherwise designated are those appearing on the cited document; those designated "RR" are by the author of this report. No "RR" evaluation is given when the author agrees with the evaluation on the cited document.

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2. US Time Corporation. Subminiature Precision Rate Gyroscopes, Technical Data Handbook SA78A-2, New York, nd, p. 1-1. U.

3. Bell Telephone Laboratories, Inc. Guided Missile System, XSAM-A-7, Missile and Booster, Missile Guidance Section, G-S-15660 Maintenance Notes, vol 11.2, revised 15 Oct 53, 2d printing, sec VIII. C.

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4. Bulova Research and Development Laboratories, Inc. (3, above), p. IV-2. C.

5. Aerophysics Development Corp. Summary Report on the Dart Anti-Tank Missile, Phase III, April 1, 1954 to February 1, 1955, rpt no 1003-3-R5G, Part 2, 1 Feb 55, Appendix III, p. 3. C.

6. Minneapolis-Honeywell Regulator Company, Aeronautical Division. ADC107 11-53, Honeywell Gyros, Apr 55. U.

25X1A 7. [redacted]

8. Ibid., p. 47. S.

9. Ibid., p. 27. S.

10. "US Experts Laud Soviet's Industry," New York Times, 20 Dec 55. U.

11. 25X1A [redacted]

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13. 14. 25X1A [redacted]

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25X1A 17. [redacted]
25X1A2g 18. [redacted]
19. Ibid., p. 61. S.
20. Ibid., p. 70. S.
25X1A2g 21. [redacted]
22. [redacted]
23.
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24.
25.